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TELEGRAPHIC CONNECTIONS

EMBRACING RECENT METHODS IN QUADRUPLEX TELEGRAPHY

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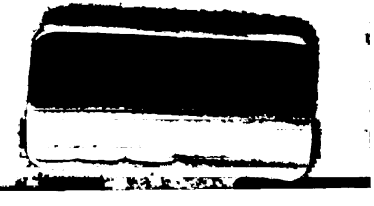

TELEGRAPHIC CONNECTIONS:

EMBRACING

RECENT METHODS

IN

QUADRUPLEX TELEGRAPHY.

BY

CHARLES THOM AND WILLIS H. JONES.

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PREFACE.

A NEW work in the field of Practical Telegraphy should possess some features which do not belong to other publications.

It has been the aim to make plain the working details of the different forms of apparatus rather than fill the pages with pictures of instruments, with the general appearance of which the telegrapher is already familiar.

It sometimes happens that if one undertakes to trace the wiring on a diagram he soon finds himself in a maze of cross-connections; or, if he finds his way out, he arrives at a thumb-screw, and can go no farther. It has been the effort to minimize the number of cross-connections in these plates, to carry the wires through the instruments; and in order that the reader may the more readily grasp the idea in the different diagrams two, and in some plates three, distinct colors have been used.

But the principal reason for the publication of a new work is the continued improvement in telegraphic apparatus and methods, and in the new applications of the dynamo to telegraphic uses since the last publication in this field was issued. It has been the special aim of the authors to delineate and describe new methods, including those of the Postal Telegraph and the Wheatstone Automatic. It brings the reader abreast of the times in matters pertaining to Practical Telegraphy.

For favors received, the authors make with pleasure the following acknowledgments: To the Editor of the *Electrical Age* for the use of an article Jan. 23, 1892, on the Postal Plant of the St. Louis office; to the Editor of the *Electrical Engineer* for the use of an article by Mr. A. S. Brown, Jan. 27, 1892, on the New Western Union Equipment; to Mr. George A. Hamilton for helpful hints in the course of revision; and to Mr. William Finn, of the Quadruplex Department, 195 Broadway, for suggestions embodied in the text on the Polar Duplex and Quadruplex, and for the pages descriptive of the Wheatstone Automatic.

It is hoped that the members of the craft will regard with favor, and find satisfaction in, this effort to delineate by pen and pencil the working methods and recent improvements in an art which has contributed so largely to make the present age what it is, and one which cannot fail to have an ever widening use and interest.

NEW YORK, March 21, 1892.

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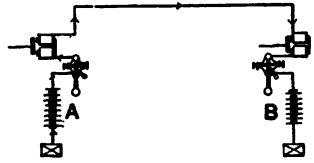
INTRODUCTORY.

BEFORE entering upon the subjects presented in the descriptive text, it is necessary that reader and writer should meet on common ground. We will consider first the ordinary Morse single line because, by so doing, we come face to face with certain terms, facts, and laws which are constantly used in dealing with electrical subjects, and upon which the Science of Electricity is built.



The diagram represents a telegraph *circuit.* In it the conventional direction of the flow is taken to be from the ground to the zinc of battery *A*; from the copper of the battery through the key and relay; along the line to the zinc element of battery *B*; thence to the ground. This movement of electricity is called a *current.* The unit of current strength is the ampere.

Electricity is checked or retarded in its flow by the elements of the battery itself, and by the wire in the instruments and line. This hindrance to the flow is called *resistance*, and in a wire it is inversely in proportion to the area of the cross-section. That is to say, if a wire of a given area of cross-section has a certain resistance, a wire having twice its diameter will retard the flow only one quarter as much. The unit of resistance is the ohm

That quality of a battery which gives the characteristic movement to electricity from the copper element of battery *A* to the zinc element of *B* against the resistance is *electromotive force*, so called, but differing from other forces in that it moves electricity, and not matter. The unit of E. M. F. is the volt. The relation of the current strength to the resistance and electromotive force is expressed in the formula $C = E \div R$.

The production of magnetism in the relays, for the purpose of attracting the armature and making an audible sound, is essential to the operation of a telegraphic circuit. The seat of the magnetism is the soft iron cores in the centre of the coils; and the cause of it is the flow of electricity through the coils. Soft iron is chosen because it can be magnetized and demagnetized rapidly, and is, of all the metals, the most susceptible to magnetism. The cores may be regarded as one bar of this metal, wound with fine wire, through which a current is passed for the production of magnetic lines of force. These set out from each end of the bar in large numbers and, curving through the air, meet and form a magnetic circuit. Many of these lines, however, are lost or dissipated, owing to the great resistance offered by the air. To avoid such loss, to improve the magnetic circuit and increase the attractive power of the magnet, a shorter path through the air is provided by an arrangement of the cores which is equivalent to bending them into the shape of a horseshoe. When an armature is placed before the two ends of the core as in a relay the magnetic circuit is still further improved; the soft iron being a better conductor of the lines of force than the air. The lines of force, having a stress like that of thousands of minute strings of stretched rubber, tend to draw the armature to the cores. The check of this movement by the front-stop, and the backward pull of the spring on the armature, produce the familiar click of the apparatus.

In the construction of the relay the cross-section and length of the cores, the size of wire, and the number of convolutions for the production of certain effects are all determined in accordance with well-established magnetic laws. Any one who wishes to explore this subject further cannot do better than read S. P. Thompson's "Lectures on the Electro-magnet." Every additional turn of wire increases the magnetic effect of the current flowing through the helices, or coils; so that, to find the magnetizing force of an electro-magnet, multiply the strength of current in ampères by the number of convolutions in the coils.

On long wires where the current is weak the relay must be wound with many turns of fine wire in order to obtain sufficient magnetizing force. If the current strength is doubled, half the number of convolutions will give the same result. The Western Union single relays in common use have an average of 8500 convolutions in the coils, and the strength of current actuating them is proportioned to the resistance of the line.

In the diagram the flow of electricity along the line is from copper to zinc. Divide the line in the middle and

ground the divided ends. The current from the copper element at battery *A* now flows to the ground plate in the centre. On the other division of the circuit, the current flows in a direction from the zero point at the ground plate to the zinc element at battery *B*. These movements of the current come into play in the working of the polar duplex, and for this reason notice is called to them here. The explanation may best be sought in F. L. Pope's work, "The Electric Telegraph," par. 145, on the Fall of Potential in a Closed Circuit.

The simple method of telegraphy illustrated in the diagram was the only one in general use as late as 1872. It has since been supplemented and supplanted by other and more complex systems which it is the purpose of this work to explain in detail. The rapid increase of the number of wires throughout the country made it necessary to adopt some system by which telegraphing could be carried on in both directions over one conductor at the same time. The first practical solution of this problem was the duplex of Stearns, with its differential non-polarized relay, first operated on comparatively short circuits in 1868. Later the effects of the static discharge on the Stearns relay on long lines was eliminated by the use of the condenser. In regard to this invention we quote from Mr. F. L. Pope: "By this admirable application of a scientific principle, in a manner no less ingenious than simple, it is not too much to affirm that the commercial value of the aggregate telegraphic property of the world was more than doubled at a single stroke."

The Stearns duplex first operated successfully on long lines in 1872 was superseded nine years later by the polar duplex. The characteristic instrument of the latter system, viz., the polar relay, differs from the ordinary Morse relay in the fact that its signals are produced by the movement of a magnetized armature, from one point to another, under the control of a current-reversing instrument at the distant end. To understand this relay, therefore, we must examine a characteristic feature of magnets not yet touched upon, viz., their poles and the rules which govern their production under the influence of a current.

PLATE I.

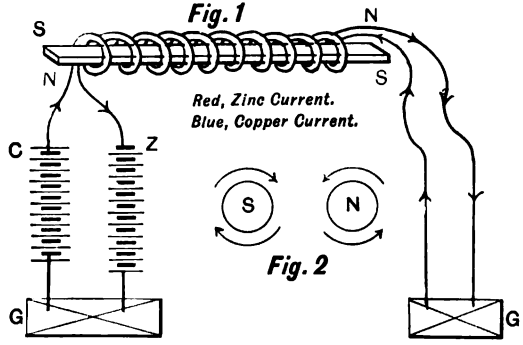


Fig. 1

Red, Zinc Current.
Blue, Copper Current.

Fig. 2

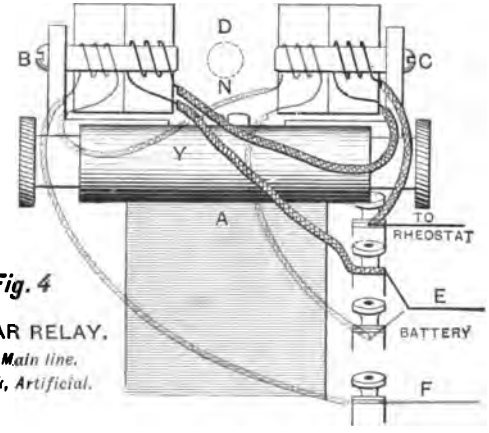


Fig. 4

POLAR RELAY.

Red, Main line.
Black, Artificial.

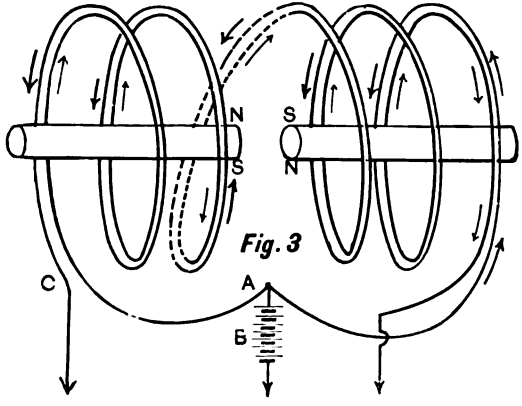


Fig. 3

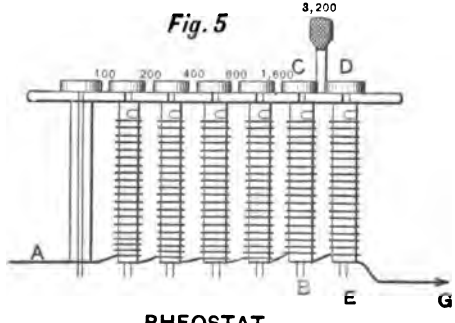


Fig. 5

RHEOSTAT.

THE POLAR RELAY.

PLATE I FIG. 1 shows a bar of soft iron wound around with two insulated copper wires of equal size and length. If a current flows through either of these wires it will cause magnetic poles of opposite properties to appear at the ends. The relation of the poles thus produced to the magnetizing current is expressed by the rule: *Looking at the bar* 'end on,' *if the current flows clock-hand-wise the near end will be a south-seeking pole; the far end, a north-seeking pole; vice versâ if the current flows anti-clock-hand-wise.* Fig. 2 shows this graphically. For brevity these poles are called the *S* and *N* poles. The colored lettering in Fig. 1 shows the resultant poles when the corresponding wires are attached one after the other to their batteries. If two batteries of equal strength are connected to the wires at the same time, there will be no magnetism apparent in the bar.

Now bisect the bar (Fig. 3). According to the 'clock-hand' rule, the colored lettering in the gap will show the resultant poles when the corresponding wires are connected one after the other to the battery. Suppose, for instance, that the blue wire is detached and the current flows through the black line only. The black letters *N* and *S* will then indicate the poles in the gap; and a knife-blade having *N* polarity, introduced into the space, will be repelled from *N* and attracted to *S*. If the current flows through both wires, no magnetism whatever will appear in the gap, because the magnetic lines of force neutralize each other.

But suppose we introduce at the point *C* in the blue line the zinc pole of a grounded battery equal in strength to battery *B*, which has copper to the line; we shall then double the current in the blue line. The blue *N* pole will have double the magnetic strength of the black *S* pole; and the blue *S* pole double the magnetic strength of the black *N* pole. A knife-blade, with a slight *N* polarity, will consequently be repelled from the blue *N* and attracted to the blue *S*.

Thus, having explained the principle which underlies the working of the polar relay, we are prepared to consider

other prominent features of the system, in order to understand the relations of its various parts and their methods of operation.

In Fig. 4, *A* is one end of a thick strip of steel bent into the form of a three-quarter segment of a circle thus: ◡. *Y* is a tubular yoke of the same material in which are "right and left" screws, to which are attached two rectangular steel brackets. To the upper ends of these at *B* and *C*, are screwed two soft iron cores around which the wires are wound, as shown in the drawing. In a gap between the cores is a dotted circle, representing the free end of an armature of soft iron hinged to the other end of the strip of steel (not shown in the drawing). The circular strip of steel is a permanent magnet which communicates magnetism of one polarity to both cores; and magnetism of an opposite polarity to the free end of the armature. When there is no current in the coils to disturb the magnetism of the cores the armature *D*, being of opposite polarity, will cling indifferently to either core as placed. Attach a ground wire to the free ends of the black and red wires, and connect a powerful battery to the wire which divides at the point *E*, and we can reproduce precisely the effects described in connection with Fig. 3.

But before proceeding further, it will be well to describe the apparatus represented in Fig. 5 and explain its use. As may be seen in the diagram, it consists of a box of insulated wire coils, the lower end of each coil being connected with a brass rod terminating in a brass disk on the top. The brass rod is insulated from the coil by a wooden tube. The brass disks are segmented to admit pegs, when it is desired to connect them. The instrument is called a rheostat, which means 'current retarder.' Over the disks will be noticed the figures 100, 200, 400, etc. These indicate the resistance of the several coils expressed in the unit of resistance, the ohm. The wire generally used in duplex circuits is No. 6 (Birmingham) gauge and has a resistance of 9.5 ohms per mile. The first coil of 100 ohms, therefore, retards or resists the current just as much as 10 miles (nearly) of No. 6 iron wire would. The current enters at *A* on the left and, passing up to the bight or loop at the top of the first coil, returns upon itself to the bottom, thence into the next one. A coil so arranged is said to be double wound. Its purpose is to eliminate inductive effects; because a current doubled back upon itself exerts no force upon external objects. From *A* the current passes uninterruptedly through the series of coils till it reaches the point *B*. At this point, one coil only remains to be traversed but as, by the insertion of a peg, the current has a much shorter path

through the disks *C* and *D*, it will flow through the brass rod to *C* across to *D*, down the brass rod to *E*; thence to the ground. Withdraw the peg and the current must traverse the entire series aggregating 6300 ohms resistance, or the equivalent of 663 miles of No. 6 wire. Connect a main line of this length to the point *F* in Fig. 4. Also connect the rheostat to the wire so marked and the copper pole of a powerful battery to the point *E*. The resistance of the two circuits being equal, the current will divide equally between them, and its effects on the core will be found to be the same as those already indicated in connection with Fig. 3. That is, the opposite polarities in the core neutralize each other and, of course, have no effect on the armature.

Now connect to the distant end of the line an equally strong zinc battery. The current in the red line is double, and has a magnetic effect twice that of the one flowing in the black line. The armature *D*, which has *N* magnetism, is attracted by the core *B* and repelled by the core *C*. By this action the local circuit is closed and a signal recorded. If we reverse the battery at the distant end, we have a copper pole at one end of the line opposed by a copper pole of equal strength at the other. This reversal at the distant station should open the home relay, but there is now no current whatever flowing in the main line. The armature is therefore repelled from *B* and attracted to *C* by the current in the black or artificial line, which flows anti-clock-hand-wise round the core *B*; and clock-hand-wise round the core *C*. By this action the relay is made to open.

At the instant of the reversal of the poles, there is a moment when there is no current in either the main or artificial lines and, consequently, no magnetic effect. During this interval the permanent magnetism of the steel circle comes into play, and prevents the armature from giving a false signal by holding it to the core at which the strongest current left it, until the reversed current magnetizes the cores.

We have therefore, in the polar relay, the conditions essential to the working of a duplex system. The reversals of the current at the home station have no effect on the home relay. It responds only to those of the distant station.

THE POLE CHANGER.

It must be already obvious that, for the operation of a polar duplex, we must have at each end a current-reversing instrument. If the reader will turn to Plate III, he will see on the right a pole-changer of the 'clock-face' variety, which is the one generally used in connection with chemical batteries.

The little square in the centre of the circle is the end of the lever controlled by a key and electro-magnet. When the key is worked, the lever which carries the ground wire alternates between two springs, to which the copper and zinc poles of the battery are separately attached. A pair of insulated stops connecting with the main line are so placed that copper to the line, zinc to the ground and zinc to the line, copper to the ground, result from the open and closed position of the key, respectively. And these motions can be effected without any break in the continuity of the circuit, which is a decided advantage.

This form of pole-changer answers very well for a chemical battery, but is not adapted for dynamo currents, because of their tendency to form an arc through its continuity-preserving contact points. The new pattern, known as the 'walking-beam' device, is shown in Plate II, Fig. 1. The dynamos send a zinc and copper current to the left- and right-hand posts, respectively. In both wires will be noticed a lamp. It has a resistance of 600 ohms, and its purpose is to prevent injury to the armature coils of the dynamo through overheating in case of a short circuit; and at the same time, to lessen the tendency to spark at the moment the line contact is broken. Contact with the line is made through the lever to which the main line is attached. The lever is controlled by a key and electro-magnet. When the key is closed, the *B* end of the lever touches the post and the zinc pole is presented to the line, the copper pole of the dynamo being grounded. When the key is open, the *C* end of the lever touches its post, and the copper pole of another dynamo is presented to the line, the zinc pole being grounded.

Fig. 2 illustrates a useful device of Mr. O. K. Newton of New York, for minimizing or entirely eliminating the excessive 'sparking' which usually accompanies the reversal

PLATE II.

Fig. 1

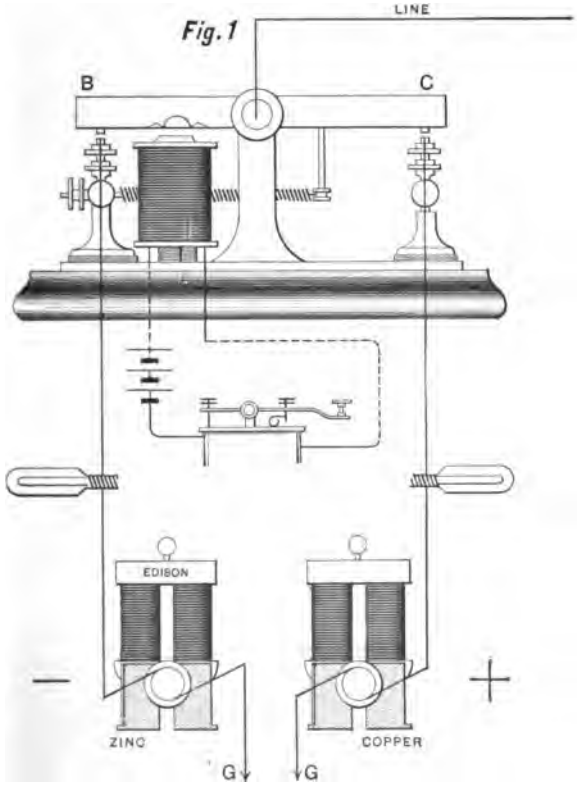


Fig. 2

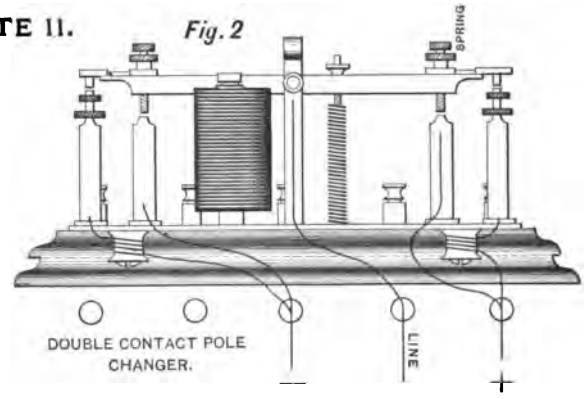
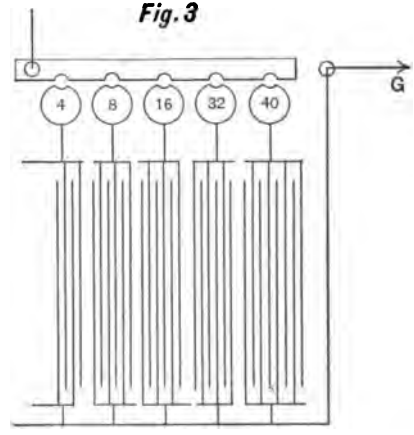


Fig. 3



of a high potential current at the contact points of the pole-changer. This is accomplished by the momentary introduction, near the contact points of the pole-changer, of an extra resistance between the dynamo and the main line. There is an extra post for each pole of the battery. In the diagram is shown the coil of 1500 ohms resistance, by which the current is retarded at the instant of the 'break' of the inner contact, and before the final 'break' at the outer contact occurs. The tendency to spark is thereby greatly lessened. It requires, however, a very careful adjustment to make it efficient.

A very essential adjunct to the operation of a duplex is the Condenser Plate II Fig. 3. Its form is that of an oblong box, on one end of which is a segmented brass bar to which the line wire is connected, and disks for convenience in adjustment. The box is filled with sheets of tin-foil interleaved with paraffine paper, represented by the lines and spaces, respectively. The sheets are connected alternately to the disks and to the ground wire; but the disk, or line, sheets are grouped in such a way that the superficial area of tin-foil in actual use may be varied at pleasure. The figures on the disks represent the percentage of the entire area to be connected with the line by the insertion of pegs.

Its action is as follows: Suppose a current from a positive pole to be admitted through the bar and peg to disk 4. It will distribute itself over the sheets attached and, by inductive action across the paper, will attract to itself an equal and opposite charge on the corresponding ground sheets. So long as the current continues on the line these two charges, in their effort to unite, will condense and become fixed upon the adjacent surfaces, so that neither can be released without the other. This action may go on until a high degree of condensation is attained. But the moment the charging current is broken the fixed polarities are released; and the discharge which then occurs is utilized for a purpose which will be explained in connection with the description of the polar duplex which follows.

On one end of the condenser will usually be found a stamp like this: 2.5 M. F. The micro-farad (for which M. F. stands) is the one-millionth part of a farad, the unit of electro-static capacity. So that, if pegs are inserted between the bar and the disks marked 4, 16, and 40, just 60 per cent of the area of tin-foil is in use, and the discharge to the line will be 60/100 of 2.5 M. F. or 1.5 M. F. Condensers, however, may be made of any desired capacity.

THE POLAR DUPLEX.

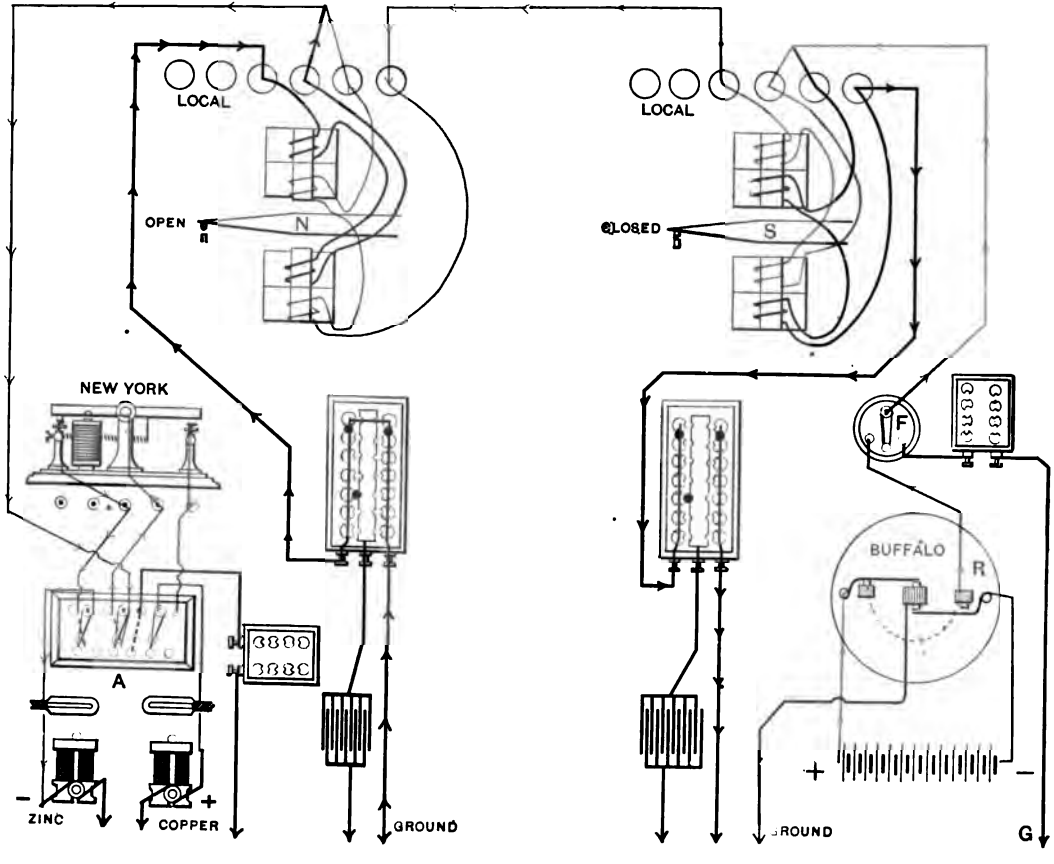
PLATE III is a diagram of the polar duplex circuit complete. Every instrument has already been described, with the exception of the dynamo switch. Its purpose is to provide a means for quickly cutting off the currents from the pole-changer when they become short-circuited, or when any adjustment or cleaning of the points is required. The centre strip is a ground switch similar to the one marked F at the Buffalo end.

The characteristic instrument—the polar relay—is drawn out of all proportion to the others in order that we may trace more clearly the current effects. The relay may be wound in various ways. The wires may be wound side by side throughout the length of the coil; or in independent coils having a common centre; or, as in the diagram, in equal compartments created by planes at right angles to the core. Each compartment contains 2400 turns of wire and has a resistance of 200 ohms, equal to 21 miles (very nearly) of No. 6 gauge wire. Before a duplex is ready for work, it must first be 'balanced.' In connection with Plate I. Fig. 4, we made the resistance in the rheostat, or artificial line, equal to that of the line. When this is done, the duplex is 'balanced' so far as the resistance of the line is concerned.

To balance a duplex, ask the distant station to 'ground,' which he does by turning the switch lever to the point *F*. Ground the wire at the home switch. The home and distant batteries are now cut off. At the Buffalo end a resistance has been introduced to compensate for the absence of the battery resistance. At the New York end this resistance is represented by the lamp. Centre the relay by adjusting the armature so that it remains indifferently at either contact point; or vibrates freely under the influence of whatever inductive effects may exist. Now 'cut in' your battery by turning the middle lever *A* of the home switch from the right, where it was grounded, to the left as in the diagram.

Adjust the pegs in the rheostat until the armature again vibrates as freely as before. Next, tell the distant office to 'cut in' and write. Now make dots on the home key. Should this cause the home signals to interfere with the incoming ones ask the distant office to close his key which

PLATE III.


LOCAL
OPEN
N
NEW YORK
A
ZINC
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GROUND
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CLOSED
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BUFFALO
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GROUND
G

will close the home relay. Now every time you close your key a false signal or 'kick,' as it is called, will be heard on the relay. It is caused by the static discharge of the line through the main line coils (red) the moment like poles of the home and distant batteries are presented to the line. There is nothing in the artificial line to counteract the discharge, because a box of fine wire coils has no electro-static capacity. The remedy is, therefore, to send a similar discharge in an opposite direction through the artificial line coils (black) of the relay. At this point, is utilized the discharge from the condenser mentioned in the description of that apparatus. It is shown in the diagram with one group of sheets connected together and grounded; the other group being connected to the bar of the rheostat. Insert a peg between the third left-hand disk and the bar, thus completing the circuit through a resistance. The condenser will then discharge into the relay in an opposite direction to, and simultaneously with, the discharge from the line. The resistance coils in the condenser circuit are for a purpose which will be explained in connection with their similar use in the Quadruplex. Now with the distant key closed, and while dashes are being made, adjust the pegs in the disks at the end of the condenser until the 'kick' disappears entirely.

We have now, by means of the rheostat and condenser, reproduced in the artificial line precisely the conditions of the line both as to resistance and electro-static capacity. The duplex is 'balanced;' and, the same process having been gone through at the other end, is ready for work. In duplex signalling there are four combinations of current which, with their effects, are indicated in the following schedule. The + and − signs represent copper and zinc to the line, respectively. The home and distant batteries should be equal in strength.

N. Y. Key.	To Line.	Buffalo Key.	To Line.	Buffalo Relay	N. Y. Relay.
1. Closed	−	Closed	−	Closed	Closed
2. Open	+	Closed	−	Open	Closed
3. Closed	−	Open	+	Closed	Open
4. Open	+	Open	+	Open	Open

The colored plate III shows the third combination with its effects on the relays; the reason for which the student, by the aid of the 'clock-hand' rule, should now be able to trace out for himself. The second combination is merely the converse of the third. The first and fourth combinations invariably puzzle beginners although, in reality, the simplest. In neither combination is there any current on the main line,

because like poles are to the line. By the first combination of zinc to the line at both ends, both relays are closed by the currents in the artificial line. At the New York end, a current flows in a direction from the ground plate through the rheostat and relay to the zinc pole. Its course is the same as that shown by the black line of arrows in the diagram; only, in this case, there is no current on the main line. By the 'clock-hand' rule it closes the relay, the armature having N magnetism. At the Buffalo end we have, for the sake of variety, a relay whose a mature has S magnetism requiring connections different from those of the home relay. Here also, with zinc to the line at both ends, a current flows from the ground to the zinc in a direction opposite to that of the black line arrows in the diagram and, by the 'clock-hand' rule, closes the relay. The student should now be able to trace out for himself every combination of current in the schedule and the reason for its effects on the relay as there indicated.

THE QUADRUPLEX.

THE success of the Stearns duplex in 1872 proved a stimulus to further advance in the same direction. In 1874, Thomas A. Edison and George B. Prescott jointly devised and put into operation the double duplex, better known as the quadruplex. If the reader has studied the details of the polar duplex and familiarized himself with the combinations of current, tracing out their effects as given in the schedule, he will have little difficulty in grasping the theory of the quadruplex ; for it is in reality very simple. The complex appearance of the set, as connected up in practice, arises from the addition of the current-distributing apparatus ; and from devices placed in the circuit to remedy certain defects, such as will be considered later on.

In the introductory chapter is a diagram of an ordinary circuit to which we will revert. The relays, if of the common type, have a resistance of 150 ohms and are worked with a battery, say of 140 cells, at each end. If a relay wound to 75 ohms is placed in the circuit you may, by giving the spring sufficient tension, prevent it from responding to the closed key, as explained in the introductory chapter. Increase the battery, to say twice the number of cells, and it will close. If the coils are wound differentially, like those of the polar relay, and inserted in the duplex circuit the magnetic effect of the home battery upon it being *nil*, its armature is left free to respond to the variations in the strength of the current from the distant end. These variations are produced by a transmitter placed in the circuit between the battery and pole-changer. When open, only a portion of the battery goes to the line ; when closed, the entire battery is in circuit. These movements are, in the quadruplex, the analogue of the open and closed key on a single wire. For this reason, the side on which this relay works is called the 'common' or 'neutral' side ; and sometimes the 'No. 2' side. All of these names are also applied to the relay itself. When both ends of a polar duplex circuit have been made to include a neutral relay and a transmitter, we have all the instruments essential to the quadruplex in its simplest form. It is the combination of two methods of duplexing. One system employs a cur-

rent-reverser to operate a polar relay, which responds to changes in the direction of the current only; the other system utilizes, for closing and opening a common relay of low resistance, the increment and decrement of current produced by a transmitter.

Plate IV represents a quadruplex circuit complete; so far as the essential apparatus is concerned. It is the polar duplex with the additions as described. In connection with the neutral relay is a third coil and condenser circuit, the purpose of which will be explained later on. If the student is perplexed by these additional coils, and by the more complicated wiring of the dynamo at the New York end, he may find a way out of his difficulty by pursuing the following course.

Take a sheet of paper at least the size of the plate. Trace from the plate or draw in pencil the right hand, or chemical, end of the quad. Bring the wire straight from the switch *M* to the split at relay *L*, as in Plate XVII Fig. 3, omitting the extra coil and condenser circuit. Fold the drawing over and reproduce it in reverse by rubbing on the back with a smooth hard surface. He has now the quadruplex circuit complete, with chemical batteries, and without any perplexing adjuncts.

The battery is 'tapped' one third of the way from the end, and the 'short end' thus created is led through a resistance equal to the remaining two thirds of the battery to the lever of the transmitter.

The left-hand end of the battery is led to the transmitter post through a rheostat for occasional use. The tapped portion and the entire battery are called the 'short end' and 'long end' respectively. When the transmitter is closed the 'long end' goes to the line, closing the distant neutral relay; when open the 'short end' goes to the line, through the lever and tongue of the transmitter, opening the distant relay. From the transmitter the battery wires pass to the pole-changer, by which the direction of both the 'short' and 'long' end can be reversed, with the effect of operating the distant polar relay. *M* is a three-point switch for grounding, *L* is the neutral, *K* the polar relay; the characteristics of each of which should now be sufficiently understood. The neutral relays of this pattern have 1800 convolutions or turns of wire in each compartment of each spool, with a resistance in each of 150 ohms; making in each differential coil a resistance of 300 ohms. The third coil has a resistance of about 450 ohms with 1800 convolutions in each compartment; making a total of 10,800 convolutions in the relay. The polar relays of this pattern have 2400 convolutions in each compartment of each spool,

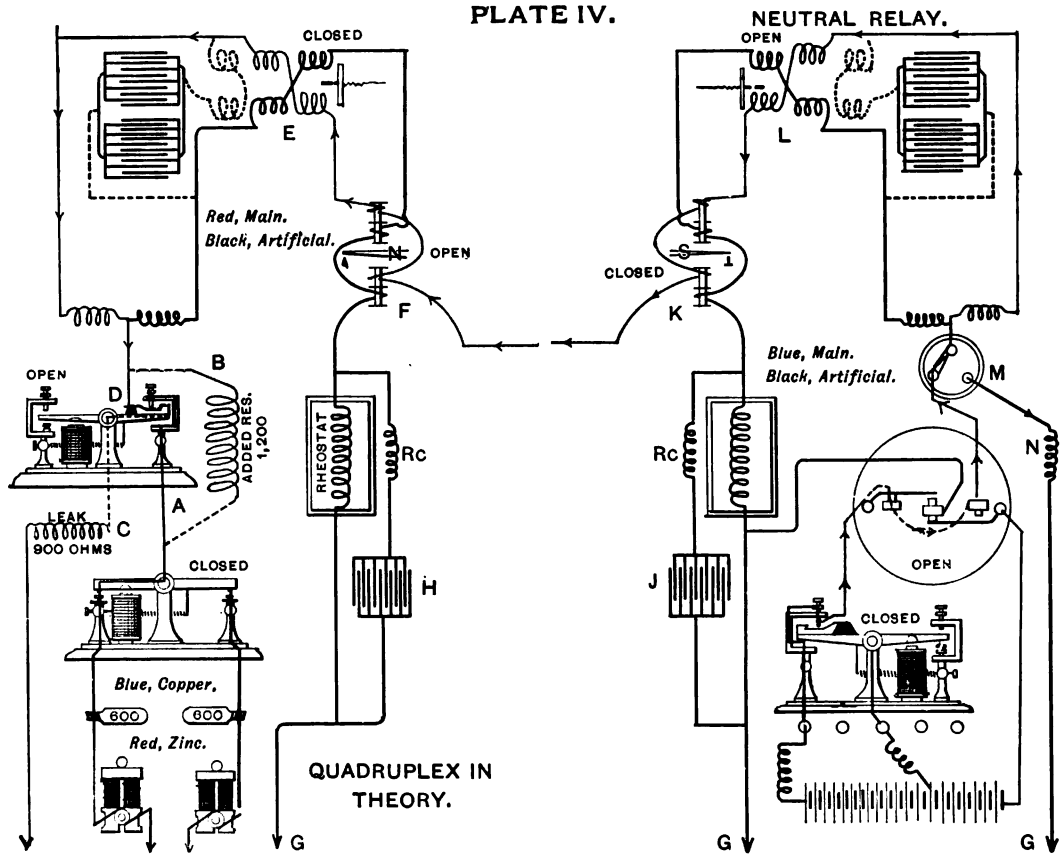


PLATE IV.
NEUTRAL RELAY.
CLOSED
E
Red, Main.
Black, Artificial.
OPEN
F
OPEN
B
D
ADDED RES. 1,200
A
LEAK
900 OHMS
C
CLOSED
Blue, Copper.
600
600
Red, Zinc.
RHEOSTAT
Rc
H
G
QUADRUPLEX IN THEORY.
OPEN
L
CLOSED
K
Blue, Main.
Black, Artificial.
M
N
Rc
J
OPEN
CLOSED
G
G

with a resistance in each of 200 ohms; or in each differential circuit 400 ohms; with a total of 9600 convolutions in the relay.

When the quadruplex is balanced, as we will suppose it to be, the home current passes through both relays without effect; leaving them free to respond to the distant reversals and increase. To the copper and zinc currents of the polar duplex we have now added the characteristics of weakness and strength, created respectively by the open and closed positions of the transmitter; so that, instead of four combinations of current as in the duplex, we now have sixteen which may be tabulated as in the schedule at the top of next column.

This table shows all the combinations of current possible to the eight instruments (four at each end) of the quadruplex. It shows also the effect, at the distant end, of each movement of each instrument; so that it is a complete chart of the working quadruplex. By means of it, with what he already knows of the polar duplex, the student can trace out for himself the cause and effect of every movement possible to the instruments. In the chart "Cl" indicates a closed transmitter with the entire battery to the line; "Op" an open transmitter with the short end to the line. Copper or zinc to the line, i.e., the open or closed pole-changer, is represented respectively by the + and − signs. It will be noticed that the last eight of these combinations are the converse of the first eight; the ninth being the converse of the eighth; the tenth of the seventh, and so on.

	N. Y. Trans.	Buffalo Neut. R	N. Y. Pole Ch.	Buffalo Pol. Rel.	Buffalo Trans.	N. Y. Neut R.	Buffalo Pole Ch.	N. Y. Pol. Rel
1	Cl	Cl	−	Cl	Cl	Cl	−	Cl
2	Cl	Cl	+	Op	Cl	Cl	−	Cl
3	Cl	Cl	−	Cl	Cl	Cl	+	Op
4	Cl	Cl	+	Op	Cl	Cl	+	Op
5	Op	Op	−	Cl	Cl	Cl	−	Cl
6	Op	Op	+	Op	Cl	Cl	−	Cl
7	Op	Op	−	Cl	Cl	Cl	+	Op
8	Op	Op	+	Op	Cl	Cl	+	Op
9	Cl	Cl	−	Cl	Op	Op	−	Cl
10	Cl	Cl	+	Op	Op	Op	−	Cl
11	Cl	Cl	−	Cl	Op	Op	+	Op
12	Cl	Cl	+	Op	Op	Op	+	Op
13	Op	Op	−	Cl	Op	Op	−	Cl
14	Op	Op	+	Op	Op	Op	−	Cl
15	Op	Op	−	Cl	Op	Op	+	Op
16	Op	Op	+	Op	Op	Op	+	Op

The diagram represents the position of the instruments in the seventh combination, viz., the New York transmitter

open and pole-changer closed; the Buffalo transmitter closed and pole-changer open. New York's open transmitter reduces the current, thus opening the Buffalo neutral relay; but the New York closed pole-changer, with zinc to the line, closes the Buffalo polar relay.

In those combinations where like poles are to the line, and therefore no current flowing through it, the relays respond to the current in the artificial line as already explained in connection with the schedule for the polar duplex.

LOCAL CONNECTIONS.

The local connections of the neutral relay are rendered more complex than those of the polar by the use of a repeating sounder, represented in Plate IX, Fig. 1. By tracing the connections it will be seen that it is placed in circuit with the back points of the neutral relay, and made to repeat into an ordinary sounder. The reason for its use is this: If, during the reversals at the distant end, the armature of the *closed* neutral relay is closely observed there will be noticed a slight tremor, or tendency of the armature to open as, at times, it actually does instead of being held firmly to the front stop. This action which, for convenience, we will call a lapse, is caused by the moments of no current on the line, and therefore of no magnetism in the cores, during the reversals at the distant end. If the local connections of the receiving sounder were made through the front stop, at every lapse of the armature, however slight, it would give a false signal or 'kick.' But if the connections are made through the back stop, the lapsing armature must traverse the space between the stops before it can close the repeating, and thus open the receiving, sounder. The interval of no magnetism is seldom so long as to give the armature time to do this; so that, by the repeating sounder device, the annoyance from false signals is in a great measure obviated.

This was one of the first adjuncts, or improvements, in the quadruplex; and one which has retained its place ever since its adoption. Others followed, and it is with these we have now to deal.

Up to this point we have been describing the quadruplex, as operated by chemical batteries at both ends, and in its simplest form. In Plate IV the reader will notice at the left hand, or New York, end an entirely different source of current; a different form of pole-changer; and different arrangement of the transmitter connections. He will also notice, as part of the neutral relay, a third coil; and in connection with it two condensers, and two resistance coils. To give the reason for these changes and explain these auxiliaries, separate diagrams are employed and described.

PROPORTIONAL DYNAMO CURRENTS.

ABOUT six years after the invention of the quadruplex the Western Union Company, from motives of economy in space and cost of maintenance, determined to use dynamo currents, instead of chemical, for quadruplex work. Now the current from one machine cannot be 'tapped' as a chemical battery can because the electro-motive force is all at the brush instead of being generated by a long row of cells in series. The short and long ends essential to quadruplex work, must be arranged for in some other way. To Mr. Stephen D. Field was assigned the problem, and Plate V Fig. 1 represents the solution, first practically applied in 1879. In the first place, the continuity-preserving pole-changer is discarded for the walking-beam pattern already described. The armature of the dynamo has no appreciable internal resistance, as a chemical battery has. To assimilate in regard to resistances the currents from the different sources, chemical and dynamo, there is inserted in each circuit, between the brushes and the pole-changer posts, a 600-ohm lamp. They also serve as a safeguard to the machine as stated in connection with Plate II Fig. 1. In the second place, the outgoing current is led from the pole-changer to the transmitter which, when closed, passes it direct to the dividing point or 'split' X. When open, there are placed in circuit a set of fixed resistances which jointly combine to reduce to one third of its full strength the current reaching the split at X for division between the main and artificial lines. The other two thirds is diverted into another channel. With a chemical battery, to obtain the short end is simply a matter of tapping the cells. But to produce the same effect in a dynamo current and to provide for the incoming current at the same time paths having equal resistances, with the transmitter in either position, is the problem. It requires for its correct understanding, a knowledge of the laws which govern the distribution of current in divided circuits. We will consider first the case of the outgoing current opposite in direction to that shown in the diagram. In order to deliver at the point X a current proportioned as 1 for the short end to 3 for the long end, or entire battery, it was found necessary to introduce a 'leak,' with a resistance of 900 ohms, and an added resistance of 1200

ohms in the open transmitter circuit. Both are indicated by the dotted red lines.

It does not come within the scope of this work to reproduce the formula by which this result was obtained. We can, however, test the results by the law which governs the division of the current. When a current of electricity finds two paths, its flow in each will be inversely proportional to the resistance. If one path offers two ohms resistance, and another only one ohm, two thirds of the current will flow through the latter and one third through the former. Now let us turn to the diagram and see whether, when the transmitter is open, there are two such paths provided.

The coils at the right of the drawing represent the main and artificial lines with a resistance of 3600 ohms each. The joint resistance of a divided circuit is equal to the product of the two separate resistances divided by their sum. The joint resistance of the two 3600-ohm circuits is 1800 ohms. When the transmitter is closed, the path of the outgoing current is that of a solid red line through the lamp resistance (600) + the joint resistance 1800 = 2400 ohms. Open the transmitter, and the path of the outgoing current to the point X is now through the dotted red line. The resistance in the circuit is now 2400 ohms, the same as before, viz., 600 + 1200 + the joint resistance of the three wires which branch at X, i.e., 600 ohms. The joint resistance of the two wires to the right of X is 1800; the wire XDC has in circuit a resistance of 900 ohms known as 'the leak.' The resistance of the joint paths to the right (1800 ohms) is in proportion to that of the path at the left (900 ohms) as 2 to 1. Two thirds of the current, as it reaches X, is therefore diverted through the leak to the ground; the remaining third divides equally between the two lines to the right representing the main and artificial circuits. When the transmitter is closed the entire current, as it reaches X, divides equally between the two lines to the right. So that, by means of a closed and open transmitter, the current reaches X respectively in the proportion of 3 to 1, for equal division between the main and artificial lines.

It remains to consider the case of the incoming current flowing to the zinc as in the diagram. The two paths, created by the open and closed transmitter, should have equal resistances in either position. The current has traversed the main line to the point X. With the transmitter closed, it has 600 more to traverse. With it open, it has two paths of 1800 and 900 ohms. The joint resistance of 1800 and 900 ohms is 600. There is therefore the

PLATE V.

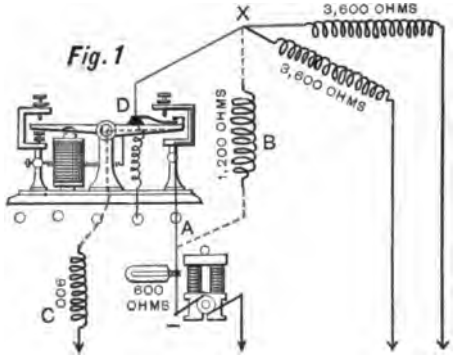


Fig. 1

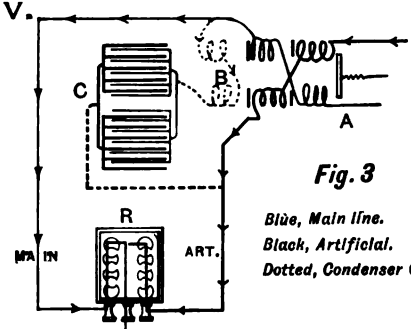
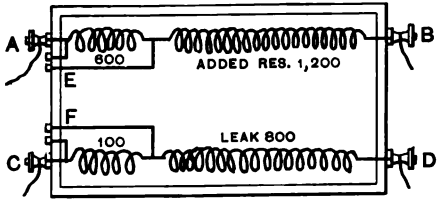


Fig. 3

Blue, Main line.
Black, Artificial.
Dotted, Condenser Circuit.

GERRITT SMITH ATTACHMENT.

Fig. 2



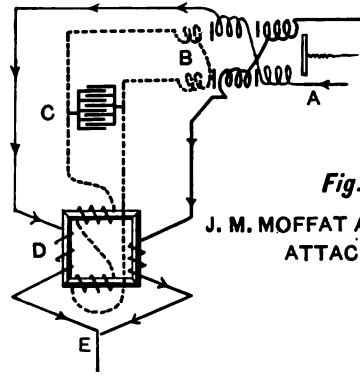


Fig. 4

J. M. MOFFAT AND BLAKENEY ATTACHMENT.

same resistance between X and the ground with an open as with a closed transmitter.

NOTE ON CURRENT DISTRIBUTION.—The problem in connection with the arrangement of resistances in Fig. 1 can be stated, and the solution arrived at, in another way. The question is not how much current there is to be divided; but how to produce at the point X a potential which, dividing into the different paths, will give a current strength to serve the purpose of a 'short end.' In the chemical system, the currents of the 'long' and 'short end' are practically from separate batteries whose potentials are in the ratio of 3 to 1 or 4 to 1. An examination of the conditions in Fig. 1 indicates that the regulation of the potential is really the aim of the device. The difference of potential between two points in a circuit produces electro-motive force, the unit of which is the volt. The potential of any given battery will fall gradually all along a line of uniform resistance until it reaches zero potential at the distant ground. A voltmeter will show a fall from the initial potential, in proportion to the resistance traversed, up to the point of insertion. For instance, if we have a battery whose potential is 300 volts at the brushes of the dynamo, the meter will show that it has fallen to 225 volts when the current has traversed one quarter of the resistance; 150 volts at half; 75 at three quarters and in like proportion to zero.

Refer now to the resistances in the diagram, the transmitter being closed. The total resistance in the line is 600 + 1800 joint resistance (of the main and artificial line) = 2400 ohms. An initial potential of 300 volts will therefore fall to 225 at X, where the current has traversed one fourth of the resistance. It then divides equally between the main and artificial lines. Open the transmitter, and the resistance is now 600 + 1200 (added resistance) + 600 (the joint resistance of 3600, 3600 and 900) = 2400 ohms as before. But at the point X the current has now traversed three fourths of the resistance, and has fallen to 75, or $\frac{1}{3}$ of 225, the figure at X with the transmitter closed. According to the formula $C = E \div R$ 225 ÷ 1800 = $\frac{1}{8}$ ampère = 125 milliampères, to be divided equally between the main and artificial lines; or 62.5 milliamperes to each. With the transmitter open, and the potential 75 at X and 600 ohms (the joint resistance of 3600, 3600, and 900) we have for current 75 ÷ 600 = $\frac{1}{8}$ ampere = 125 milliamperes, to be divided between 900 ohms in the leak and 1800 in the lines; which gives 83⅓ milliamperes in the former and 41⅔ in the latter. Divide 41⅔ equally between the main and artificial lines, and we have 20⅚ in each. Now 20⅚ milliamperes × 3 = 62.5 milliamperes, the current in the main line when the transmitter is closed. The arrangement of resistances in the diagram, therefore, by means of a closed and open transmitter, proportions the current in the main line as 3 to 1. The leak having a resistance of one half the joint resistance of the two lines receives twice the current. The waste in the leak, therefore, and the retardation in the added resistance coils are the price paid for obtaining the reduced potential at X.

It sometimes happens that better results are secured when the proportions are 4 to 1. By increasing the added resistance to 1800 and reducing the leak to 800 we obtain at the point X, with the open transmitter, a potential represented by the figures 56.25 or $\frac{1}{4}$ of 225, the figure at X with the closed transmitter. This will give us a current of between 15 and 16 milliamperes or $\frac{1}{4}$ of 62.5 (very nearly). If we

take a resistance for the main and artificial line greater or less than 3600 ohms the ratios of 3 to 1 and 4 to 1 will not be closely preserved; but it will be found to be near enough for working purposes.

Fig. 2 shows the arrangement of the added resistance and leak coils in one box as adopted in practice. In the drawing, the peg inserted at *E* makes the proportional distribution 3 to 1, the same as in Fig. 1. By changing the peg from *E* to *F*, the added resistance is increased to 1800 and the leak is decreased to 800 ohms; giving a proportional distribution of current of 4 to 1. If the reader wishes to test the fitness of this combination to deliver the current at *X* in these proportions, he has only to substitute 1800 added resistance for 1200 and 800 leak for 900 in the process already given.

THE GERRITT SMITH ATTACHMENT.

We have already spoken of the false signals given by the neutral relay at the moment of the distant end reversals and of the repeating sounder as a partial remedy therefor. This defect in the working of the quadruplex has been the subject of more remedial devices than any other part of the apparatus. Figs. 3 and 4 represent two of these devices, both of which have been in successful operation at 195 Broadway. The first one was introduced by Mr. Gerritt Smith in 1884, and is still in general use ontside of New York. As already stated, the defect is caused by the absence of the current, and therefore of magnetism in the relay cores, at the instant of the distant end reversals. The purpose of both devices is, by artificial means, to continue the magnetism in the cores and thus 'bridge over' the very brief interval between the reversals.

The Smith apparatus consists of extra coils in the relay with a resistance of about 450 ohms; two condensers, and an adjustable resistance box with two sets of coils. The mode of its operation can readily be traced in the diagram. The condensers are in a bridge, so that the home current has no charging effect on them. The distant current enters the relay at *A*, passes through the relay coils, and charges the plates of the condensers through the extra coils *B*. The instant this current ceases by reason of the distant reversal, the charge flies through the extra coils and the relay coils in a direction opposite to that of the current just ceased, and holds the armature to the magnets until the current from the distant end arrives. The two sets of resistance coils, usually of 300 ohms each, at the point of division *R*, by retarding the incoming current aid in the charge of the condensers; and also, by retarding

the discharge of the plates in that direction, increase the discharge into the relay.

Care must be taken in attaching this apparatus, to so arrange the connections that the charging current passes around the relay and the extra coils in the same direction.

Another device, of which John M. Moffatt and Edward Blakeney, of New York, are the inventors, is represented in Fig. 4. It consists of a rectangular frame of soft iron which, as set up, forms an induction coil or inductorium. Its connections and mode of operation can readily be seen. The main and artificial lines encircle opposite sides of the frame; the two remaining sides being encircled by an independent circuit through the third coil of the relay, as represented in dotted black. Through this circuit flows the secondary currents induced at the interval of 'no current' in the primary or main-line circuit. At the moment of no magnetism in the neutral relay cores, the induced current continues the magnetism in the cores long enough to prevent the armature from lapsing. To further increase its efficiency, a condenser may be placed in the circuit as represented; but in the New York quadruplexes it has not been found necessary.

THE WORKING QUADRUPLEX.

PLATE VI represents the quadruplex, with the instruments still in general use throughout the United States outside of New York. It shows the actual connections of the working 'quad.' Every instrument has already been described; and it only remains to call attention to the method of connecting up the two condensers through the retardation coils, marked *R C*, in the rheostats Each set of these has a resistance of about 150 ohms. The top condenser discharges through only one set; the lower one through both, or 300 ohms. The purpose of these coils is to assimilate the discharges from the condenser to those of the the line; to prolong the bullet-like discharges from the plates by passing them through resistances like those in the relays. The adjustment of the condensers brings us to a topic now to be considered.

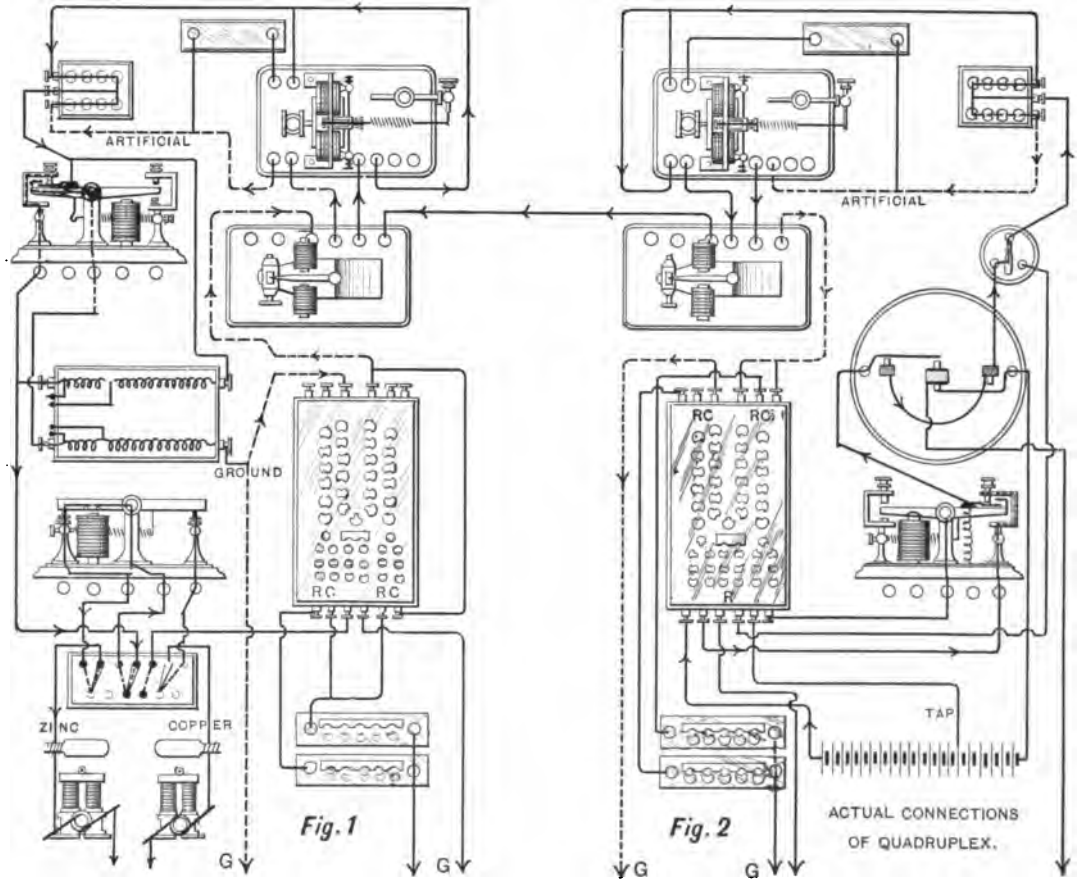
HOW TO BALANCE A QUADRUPLEX.

The wire must be grounded; first at the distant, then at the home end. Centre the polar relay so that the armature moves freely between the points. Then 'cut in' and close the key on the No. 2 side so that the current from the entire home battery may go to the line. The ordinary line balance is then obtained in precisely the same way as that of the polar duplex already described.

After the distant office cuts in and writes, if it is found that the incoming signals are more or less broken by your own writing, the static balance remains to be obtained as in the case of the polar duplex under similar conditions. The effect observed in both cases arises from the same cause, and is the result of the electro-static capacity of the wire, which may be regarded as a Leyden jar of small diameter and great length. The neutral relay is the more sensitive to its effects; and to remove the 'static' is vital to the successful working of the quadruplex. It might be eliminated from the polar relay and yet be felt on the No. 2 side; but it could not be removed from the No. 2 side relay and a trace of it be found in the polar.

Ask the distant office to open his No. 2 side. Close the home key on that side, putting the entire battery to the line. Turn down on the neutral relay until the tension of

PLATE VI.


ARTIFICIAL
GROUND
RC
RC
ZINC
COPPER
G
G
Fig. 1
ARTIFICIAL
RC
RC
R
TAP
G
G
Fig. 2
ACTUAL CONNECTIONS
OF QUADRUPLEX.

the spring is very slight. Then, while you make dashes on the polar side, adjust the pegs in the condensers until the 'kick' disappears. The condenser which discharges through the lesser resistance should have about twice as many plates as the other, because the bulk of the static discharge is usually from that section of the line nearest the home relays; while only a comparatively small discharge follows from the more remote portion of the line. To assimilate the artificial discharge to these conditions, the resistances and plates of the first and second condensers are arranged as stated.

If it is found that a certain peg appears to give too much, and the next too little, it is probable that the condenser discharges either too quickly, or too slowly, to meet the line discharge at the right moment. In this case, first adjust the condenser as nearly as you can, and then vary the resistance in the retardation coils until the desired result is obtained.

After the 'static' has been removed, ask the distant office to write on his No. 2, and dot on his polar side. Close your No. 2 side, and adjust the neutral relay until his signals come clear while you reverse your pole-changer, slowly at first, then rapidly. It is better to test the distant signals from his writing than from his dots. The latter often come clearly when words come imperfectly, and reveal the fact of a defective line, or static, balance When making your test, reverse your pole-changer slowly and observe the distant signals a moment to make sure that they come equally clear under each reversal. In this way you may detect heaviness or lightness in the signals which, had you dotted rapidly, you might have overlooked because, by so dotting, you simply 'halved' the discrepancy. To become a quadruplex expert one must give attention to just such details as these. It is the 'little things' that combine to raise or lower the working efficiency of the quadruplex system.

QUADRUPLEX TROUBLE AND FAULTS.

A system of apparatus and connections so complex as the working 'quad' is obviously liable to derangement; and it is oftentimes important to be able quickly to locate and remedy the trouble. Although no amount of directions in this particular can take the place of an accurate understanding of the various parts of the system, and of experience in handling them, there are yet certain troubles, common to the system, of which mention can profitably be made in a work of this kind.

For instance, it sometimes happens, especially after a

thunderstorm, that the paper dielectric in the condenser has been pierced, bringing the line and the ground plates together. This will practically cut the rheostat out of circuit, and allow the current on the artificial line to go unimpeded to the ground. If this is suspected, detach the condenser and take a line balance. Connect up the condenser again, and if your balance is destroyed the remedy is another condenser.

If, at some time, in taking a line balance, the resistance appears nearly twice the usual figure ask the distant end what his balance is. If it is normal his ground wire is open, or defective, and you have been getting a ground through his rheostat, thus doubling the normal resistance of the line.

It is not an uncommon occurrence for the turns of wire in the relays, more often the polar, to become short circuited, destroying the balance of the coils; or, as it is expressed, the relay becomes 'lop-sided.' In this case a balance with which the defective polar relay will work will not answer for the neutral; and *vice versâ*, if the neutral relay coils are cutting each other out in any considerable number.

Another relay trouble on multiplex circuits where grounded loops are used, as in Plate IX Fig. 1, is that the insulation of the coils and core becomes defective, allowing them to make connection with each other; thence through the local contact to the ground. If this is suspected, cut off the grounded loops and the relay will be found to work normally; but it cannot be used in a set on which a loop is worked.

It must be clear to the reader that, in a system which depends for its successful operation on the reversals and proportional increase of the current, too much attention cannot be given to the maintenance of good batteries, and of clean points in the pole-changer, and transmitter. Nevertheless, by far the greater part of the troubles on the quadruplex arise from failures and neglect in these respects. "Your reversals break up the second side" is the phrase most frequently heard and used among those who have charge of the 'quads.' When this trouble makes its appearance, ask the distant station to close his key on the second side and 'dot' on the first. Then cut off the home battery by 'grounding.' A well-developed 'kick' or 'rattle' will most likely appear on the neutral relay, caused by the interruption of the increment of current by the defective points. Or, you can test his points by asking him first to open then close his pole-changer and watch his writing on the No. 2 side. If the signals fail with either test, another pole-changer should remedy the trouble. If it does not, it

must be looked for in the distant battery. In dealing with battery trouble, a defective cell in the 'short end' will be felt when the distant office opens his No. 2 side. The current will then be too weak to work even the polar relay. If a cell in the short end is open, the entire current will be cut off, and the wire appear 'failed,' no matter what the position of the transmitter. If the cell is defective or broken in the 'long end,' the wire will appear open only when the distant office closes his No. 2 side. The signals on the polar side will not be interrupted. In neither case can the distant office produce signals on the home neutral relay.

Sometimes the 'tap wire' becomes disconnected, either at the battery or the transmitter. In this case when the distant No. 2 side is closed the polar side will work normally; but when the distant transmitter is opened the wire will appear to have failed because no current can pass from the 'short end,' through the lever of the transmitter, to the pole-changer.

The transmitter also may become a source of trouble, not to be distinguished at the distant end from battery defects, if the points are not kept clean and carefully adjusted; so that when closed the tongue and post contact breaks the lever contact, and when open the tongue and lever contact leaves the post clear. A failure in either case cuts off the increase from the main line.

In very rainy or foggy weather, it frequently happens that the escape on the line is so great that the 'long end' not only fails to work the neutral relay but the polar side cannot be worked without it. The second side is then closed and abandoned, and the 'quad' is worked duplex. In such cases, where a chemical current is used, it is desirable, in order to prevent unnecessary consumption of the battery, to introduce a resistance between the long end and the post of the transmitter. When the weather clears and the line resumes its normal condition it may be found, if an attempt is made to use the No. 2 side, that the 'margin' from the distant end is very small. If this is the case, the distant office has probably failed to remove the resistance spoken of, and the long end is weakened by its presence.

The word 'margin,' which occurs here, is often vaguely used and may convey a different meaning to different persons. Some appear to understand by it the 'long end;' others the increase of the 'long end' over the 'short.' Two well-known electricians were consulted, and agreed in defining it as the current strength over and above what is absolutely necessary to work the No. 2 relay. The practical unit of current strength on telegraph lines is the milliam-

pere. If the battery at the distant end furnishes a current of 55 milliamperes, when 45 would be sufficient to work the No. 2 relay, the 10 milliamperes is the 'margin.' In a more general sense the 'margin' is the amount of tension that can be given to the retractile spring of the neutral relay before the effect of the reversals of the distant pole-changer is apparent on the No. 2 side.

Mr. P. J. Wicks of the Quadruplex staff at 195 Broadway has suggested the following plan for experiment in connection with quadruplex trouble: Loop the line wire of a quad to a point say 250 miles away, and back to another convenient quad in the same office. Balance them as though they were distant sets. Now introduce into one set every form of interference and disconnection that could possibly occur in practice, and observe the effect on the other set. In this way one can familiarize himself with symptoms which might aid in the location of actual trouble when it occurs.

PLATE VII.

NEW POLAR RELAY.

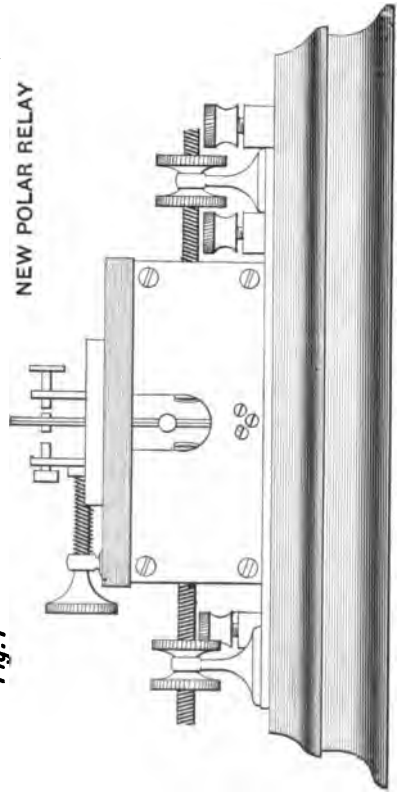


Fig. 1

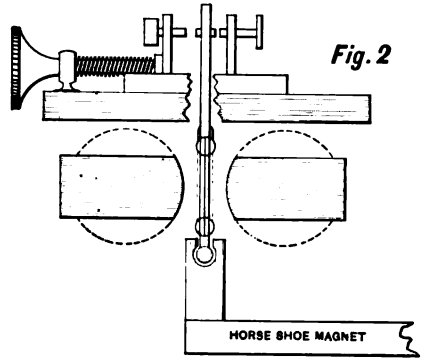
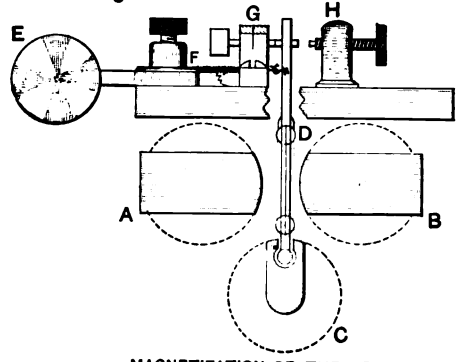


Fig. 2

MAGNETIZATION OF THE ARMATURE.

Fig. 3

SELF-POLARISING RELAY.



MAGNETIZATION OF THE ARMATURE.

NEW QUADRUPLEX APPARATUS.

THE apparatus of the quadruplex described in the preceding pages is such as has been in use for many years; in some cases, the Siemens type of polar relay for instance, ever since the invention of the quadruplex. Among those who had the care of these sets the opinion gradually gained ground that their working parts were too heavy and cumbersome, requiring the currents to do unnecessary work in moving masses of metal. An increasing knowledge of the nature and laws of magnetism made it apparent that the presence of heavy yokes, in both polar and neutral relays, greatly impaired their efficiency, causing a magnetic lag and making them less quick to respond to the currents.

In accordance with these facts, there were devised and constructed by several electricians new patterns of instruments for quadruplex work; so that the general appearance of the New Standard Quadruplex differs entirely from the old. The essential feature of course is the new relays; and the characteristics of their construction are (1) the use of aluminium in the armature for lightness; (2) better disposition of the parts for magnetic effect; (3) and most important, the absence of the yoke in both relays, thereby assisting the rapid magnetization and demagnetization of the cores. In the description of Plates VII and VIII, therefore, we have to deal with improvements in the quadruplex.

Plate VII Fig. 1 represents the general appearance of the new polar relay, nearly one-half actual size. The base is similar to that of the old patterns. The coils are enclosed in a neat brass box, with openings on either side to make visible the cores, the ends of which are shown in the drawing. The top of the box, through which the armature passes, is of rubber. The usual front and back stops, the former with a 'right and left' screw attached, complete the apparatus.

Fig. 2 shows its internal arrangement, and the new method of magnetizing the armature. Instead of the heavy three-quarter circle, as in the old form, is a simple permanent magnet of the horseshoe form, part of which is shown in the diagram. This magnet extends its poles through a hinge piece to two flat pieces of soft iron fitted one in each end of a frame of aluminium. The ends of the cores are

so placed that the armature is exposed to the attraction and repulsion of four pole pieces, instead of two as in the old relay. The coils are wound differentially in sections; each section having 2850 turns of wire, and a resistance of 200 ohms. The action of the relay will be considered in connection with the winding of the coils as shown in Plate VIII.

Fig. 3 shows the working parts of a new self-polarizing relay—the invention of Mr. S. P. Freir of the Wheatstone Department, 195 Broadway. Its general appearance is similar to that of the new polar relay, with the exception of the top. The difference in this respect is plainly shown in the drawing. The feature of the relay is the magnetization of the armature. This is accomplished by means of a third coil whose core communicates to the armature the changes in its polarity. This feature of the armature causes it to be *uninfluenced* by the reversals of current at the distant end and, therefore, fits it for a neutral or 'common side' relay. In the diagram, *A* is the repelling coil; *B* the attracting; and *C* the armature coil whose changes of polarity are in unison with those of coil *A*. *D* is the armature, having an extended arm of aluminium which gives lightness. *E* is the thumb-screw controlling the retractile spring *F*. *G* and *H* are the usual stops, the former having platinized contact points. Each half of the three spools has 2350 convolutions with a resistance of 133⅓ ohms, making a total resistance of 400 ohms each in the main and artificial circuits. The windings of the coils and the mode of operation will be considered in connection with Plate VIII.

THE NEW STANDARD QUADRUPLEX.

PLATE VIII represents the New Standard Quadruplex of the Western Union Company in which are incorporated the latest inventions and improvements. Every instrument is new either in design or invention. The block for the dynamo switch is of slate, instead of wood as formerly. The brass work of the working parts of the sounders, pole-changer and transmitter is of the tubular pattern for the sake of lightness. The form of the latter instrument is changed so as to make the points easy of access for cleaning. The 'disk and peg' rheostat has been discarded for the 'radial arm' pattern, in which changes in the resistance are effected by moving back and forth two brass levers having a common pivot. It takes up less space than the old pattern, and dispenses entirely with the use of pegs. It is shown on the right of the diagram. The current on the artificial line enters the rheostat at the point *A*; thence to the point *B* the pivot of a four-point switch whose lever, resting at will on *B*, *C*, or *D*, cuts in 0, 3000 and 6000 ohms respectively.

Thence to the point *E*, where it encounters a series of 400-ohm coils, till it meets the radial arms *FG*, *GH*. Then it passes through another series of 40-ohm coils to the thumb-screw at *J* and the ground. The 400 and the 40 ohm coils are each 10 in number.

The battery compensation coil and the retardation coils are placed by themselves in a small rheostat of like design with the radial. In the diagram the two outer thumb-screws are those of the 600-ohm compensation coil *AB*, in circuit only when the line is grounded. By means of the radial arms the retardation coils are made adjustable; the lower series aggregating 1000 ohms; the upper 525. Condenser *D*, which should have twice as many plates in use as condenser *C*, discharges through the point *G* and the coils to *H*; thence to the relay. Condenser *C* discharges through two sets of coils (about 150 ohms in each), entering the series at *F*; thence to the radial arm to *G*, to *H*, and out to the relay.

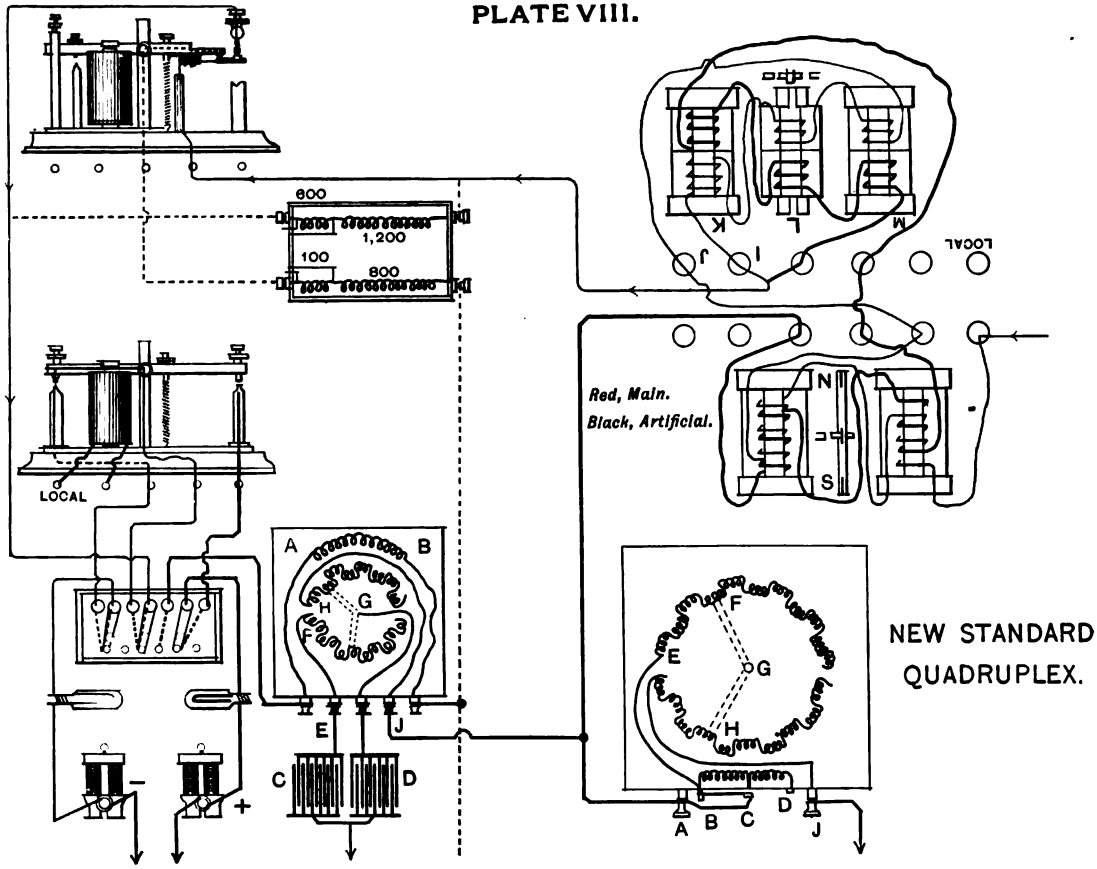
The general appearance of the new polar relay and its working parts have already been illustrated and described. The armature is exposed to the magnetic action of four

pole pieces. Let us trace the windings, the production of the poles and their effect on the armature. Suppose the upper end of the armature has *N* polarity; the lower *S*. The home copper current, for example, enters the red line at the 'split;' and, in the left-hand core according to the clock-hand rule, produces in the lower pole piece *N* polarity; in the upper, *S*. Then in the right-hand core it produces in the upper pole piece *N* polarity; in the lower, *S*. The current in the artificial line produces poles in each case equal and opposite to these; so that the armature is unmoved. Now place zinc to the line at the distant end. The poles already produced by the current in the red line are doubled in strength. The *N* and *S* in the left-hand core attract, the *N* and *S* in the right-hand core repel, the armature which closes firmly until the current at the distant end is reversed.

On the common or No. 2 side, is the new self-polarizing relay, the general appearance and working parts of which have already been described. It dispenses entirely with the resistance coils and condensers of the Smith attachment and is a new feature in quadruplex telegraphy. Let us trace the windings, the production of the poles under the influence of the current, and their action upon the armature. In the diagram, the relay occupies the position in relation to the polar relay which it would have in a working quadruplex. Let a positive current enter the relay at *I*, it creates in the core *K*, poles *N* and *S*; in core *L*, poles *S* and *N*, which are communicated to the armature; in core *M*, poles *S* and *N*. In the artificial line (black) in each case the reverse of these poles is produced, as the reader may verify for himself. Attach a zinc current of maximum strength to the distant end of the red line. Every pole is doubled in strength as compared with that of the artificial line; and they stand thus: $\begin{matrix} S\,S\,N \\ N\,N\,S \end{matrix}$ The middle letters represent the polarity of the armature which is attracted to the right. The repeating sounder is thereby opened, and the receiving sounder closed. If the currents of maximum strength are reversed the cores will be polarized thus: $\begin{matrix} N\,N\,S \\ S\,S\,N \end{matrix}$; in which again it is plain that the armature is attracted to the right with the same effect as before. The relay does not respond therefore to reversals of the current, but to the increase only. The armature changes its poles with every reversal, hence the name given to it by its inventor, the self-polarizing relay.

It will be noticed that of the three coils two, *L* and *M*, are similarly polarized and work in unison with each other,

PLATE VIII.



NEW STANDARD
QUADRUPLEX.

but in opposition to the poles of core *K*. In adjusting the relay for work, core *K* should ordinarily be placed about $\frac{1}{32}$ of an inch from the armature and core *M* about three times that distance. The decided advantage which this relay possesses over all previous ones arises from its small mechanical and electrical inertia. The mass of iron contained in the cores is small, and the magnetism developed by the current comparatively weak. But since the moving parts are light, it is of sufficient strength to actuate the armature without the development of those strong counter electromotive forces, which always retard the effects of the incoming current. The magnetism excited in the cores of this relay rises to a higher value with a given current sooner, on this account, than would otherwise be the case. It begins to act upon the armature when its intensity acquires a strength very much less than that needed to operate any other type of No. 2 relay; and it continues to hold the armature in action until the magnetism falls below that same value. Thus, the time during which the current acts is considerably prolonged; and the interval of no current, which has ordinarily to be compensated for, has no appreciable effect upon this particular form of relay.

DUPLEX LOOP CONNECTIONS.

THE descriptions of the adjuncts to the quadruplex system, delineated in Plates IX to XVII inclusive, are essential to a practical knowledge of the means by which the quadruplex service is extended to other offices than those in which the instruments are placed.

Plate IX Fig. 1 shows the connections by which the sending and receiving instruments of a duplex or one side of a quadruplex, in this case the common side, may be worked by a branch office. A small dynamo furnishes the current, which is brought up through a fuse to one post of a three-point switch, the lever of which makes connection with the instruments. The conductor branches at the point where the colors meet; and the red and blue lines respectively represent the course of the receiving and sending sides of the set and loop. From the instruments the divided current is conducted to a double three-point switch as indicated. By turning the switch levers to the left, the currents are led to the spring-jack *LS* in the loop switch, into which the branch legs are introduced by a wedge. By turning the switch lever to the right the loop is cut off; and the currents are led to the ground through lamps having a resistance equal in each case to that of the disconnected legs. The resistance of the loop and local circuits are thus equalized because the dynamo furnishes the current for a number of such circuits.

NOTE ON LAMPS IN THE CIRCUITS.—In a few preceding plates, and in a number of those that follow, will be noticed incandescent lamps inserted in the circuit. These lamps serve one of the following purposes according to their position:

1. To detect a near-by ground on the line. The lamps above the switch-board in Plate XIX serve this purpose.
2. To protect the dynamo and instruments from short-circuiting. See Plate II Fig. 1.
3. To compensate for a line or loop resistance momentarily cut off, as in Plate XI Fig. 2.
4. To equalize the resistance in a number of wires fed by one dynamo, as in Plate XIII Fig. 1.
5. To produce a fall of potential by the introduction in the circuit of a non-magnetic resistance. The lamps in Plate XV serve this purpose.

Fig. 2 shows the same duplex loop connections, the cur-

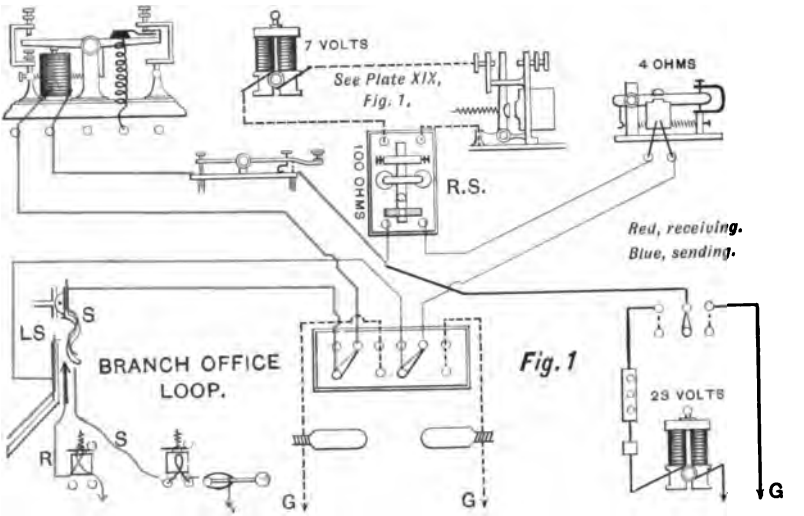


Fig. 1

PLATE IX.

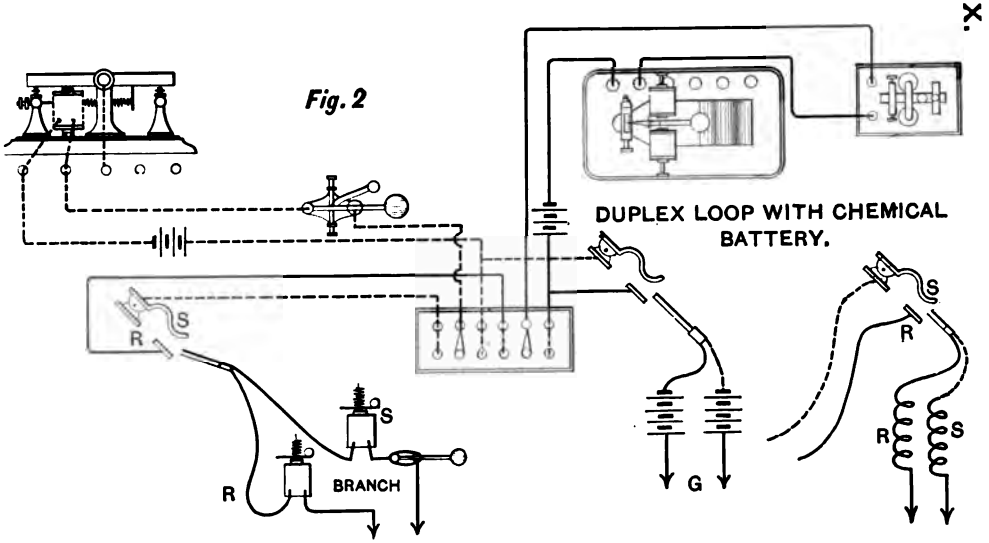


Fig. 2

DUPLEX LOOP WITH CHEMICAL BATTERY.

rent for which is furnished by two chemical batteries. In the diagram, the copper poles are grounded. The zinc poles are led to a wedge and spring-jack. From this point, the course of the receiving and sending side may be traced by the solid and dotted line respectively. As in the former desk switch, the branch office is cut in by turning the switch levers to the left. When turned to the right, the wedge batteries are opened. Two small batteries, however, remain in the local circuit, and care must be taken that they present to the jack switch opposite poles to those of the wedge batteries. Otherwise, when the branches are cut in, the local cells will oppose the loop batteries. To the right is an extra spring-jack to which, by removing the ground wires the loop batteries may be led. An extra duplex loop placed in the jack enables two branch offices to work on one duplex set.

COMBINATION OFFICE AND OUTSIDE LOOP.

PLATE X FIG. 1 shows how a 'desk,' or office, loop may be combined with a branch office to work on one duplex set. In large offices duplex and quadruplex sets are often grouped closely together for the convenience of their attendants. In order to make them available as working sets 'office loops' are run to convenient desks. In the diagram the double three-point switch and the spring-jack are identical with those in Plate IX. On the office loop desk are two separate three-point switches. By turning the levers to the left or right, the office loops may be worked in combination or independently.

Fig. 2 is a diagram of an ingenious device, known as the D. R. Downer repeater, by which a single wire to a branch office may be used to receive and transmit alternately on a duplex or, as in this case, on the common side of a quadruplex set.

The relay *R* controls, through the repeating sounder, the repeating transmitter *T*. Through the tongue and post *K* the branch wire is run to one disk of a three-point switch; through the lever to a key through the electro-magnets of the transmitter *V*; thence to the battery and ground. The battery is tapped at the third cell and led to the other disk of the switch; thence to the lever of the transmitter *T* as shown by the dotted line. It may be readily seen that, when *T* is open, the battery is cut off from the branch line. In this position of the transmitter, the tongue connects with the lever and completes the three-cell circuit, which holds the transmitter *V* closed and prevents the distant station from getting back his own signals. When relay *R* closes transmitter *T*, the entire battery goes to the branch office and the transmitter *V* being in the circuit, he has full control of the sending side.

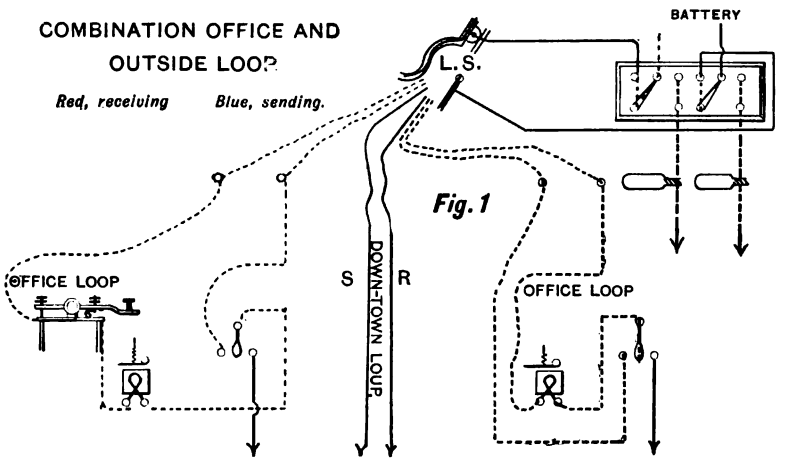
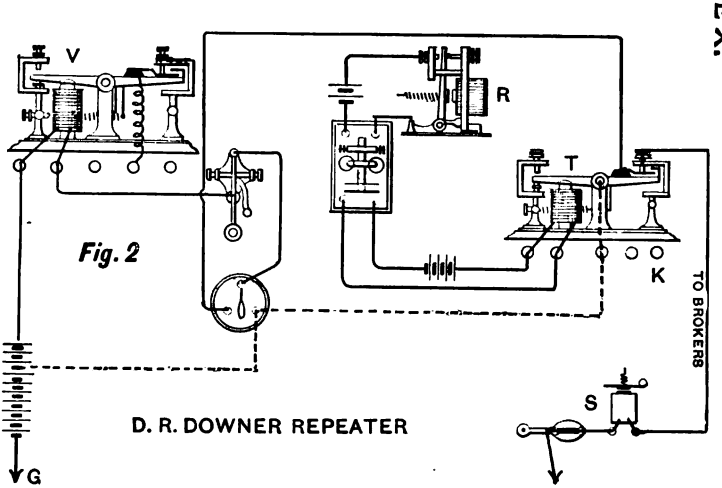

COMBINATION OFFICE AND
OUTSIDE LOOP
Red, receiving
Blue, sending.
L. S.
BATTERY
Fig. 1
OFFICE LOOP
S
R
DOWN-TOWN LOOP
OFFICE LOOP

PLATE X.


V
R
T
K
TO BROKERS
S
G
Fig. 2
D. R. DOWNER REPEATER

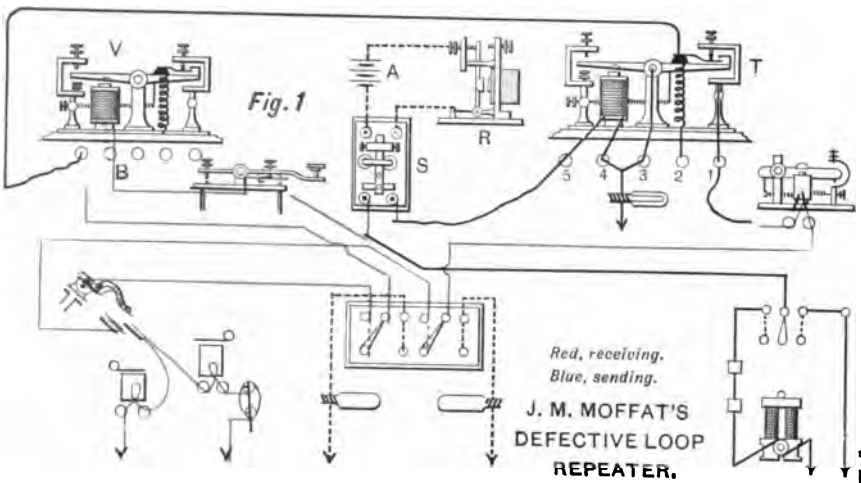
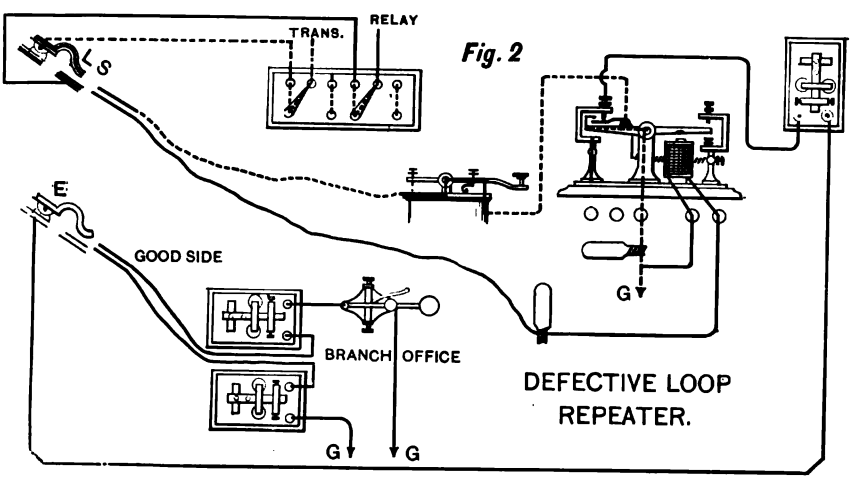

V
A
T
B
S
R
5
4
3
2
1
Fig. 1
Red, receiving.
Blue, sending.
J. M. MOFFAT'S
DEFECTIVE LOOP
REPEATER.

PLATE XI.


TRANS.
RELAY
S
Fig. 2
E
GOOD SIDE
G
BRANCH OFFICE
G
G
DEFECTIVE LOOP
REPEATER.

DEFECTIVE LOOP REPEATER.

IT sometimes happens that one leg of a loop to a branch-office fails at a critical moment. To be able quickly to connect up the intact leg of the loop and make it do the work of the Downer repeater is an advantage. Plate XI Fig. 1 represents such a device, requiring for its operation only a portable transmitter and a few short wires. It differs from the Downer repeater in that it uses both batteries of the duplex loop already at hand. In the drawing the device is connected with the common side of a quadruplex. The sending side of the loop is supposed to have failed, and is detached from the transmitter *V*. The branch office must reverse his instruments so that his key will be on the receiving side of the loop. Remove the intact leg from the repeating sounder *S* (or relay, if on the polar side), and connect it to thumb-screw No. 1, of the repeating transmitter *T*. Connect thumb-screw marked 5 to the binding-post of the repeating sounder, or relay, in place of the leg just removed. Connect thumb-screw 2 of transmitter *T* to the thumb-screw of transmitter *V*, from which the defective wire has been removed. Connect thumb-screws 3 and 4 through a lamp to the ground, and the repeater is ready for use. To save time, the connecting wires are usually attached permanently to the repeating instrument. The relay *R* controls through the repeating sounder *S*, and the transmitter *T*, through the post and tongue of which the intact leg is run, as indicated, through transmitter *V* to the dynamo. It may be readily seen that when transmitter *T* is opened, the battery is cut off from the receiving leg and grounded through the tongue and lever. In this position, the circuit which controls transmitter *V* is closed and prevented from repeating back the signals of the distant station. When relay *R* closes transmitter *T*, the current is restored to the intact side and the transmitter *V*, being in the circuit, is readily controlled by the branch office for the purpose of sending.

Fig. 2 represents the same device as arranged when permanently desked. The repeating apparatus is connected to a wedge ready for insertion in the loop-switch jack *LS*. By simply placing the loop-wedge in the extra jack *E* so that the intact side of the loop will touch the upper lip of the jack, connection is instantly made with the branch office. The action of the repeating transmitter, in opening the branch wire and keeping closed the sending transmitter in the dotted-line circuit, is the same as that already described.

DOUBLE LOOP REPEATER.

In connection with Plate IX Fig. 2, it was stated that chemical batteries could be made intermediate by removing the ground wires; and that, by means of an extra jack, two independent loops to branch offices could be connected to a duplex set and worked as companion loops. To accomplish this result with dynamo currents, is the purpose of the repeater, shown in Plate XII—the device of Mr. John M. Moffatt of New York. The arrangement of the instruments in the diagram is such as to indicate most simply the methods by which the apparatus is made to attain its purpose.

The outfit consists of four transmitters, two keys, and three spring-jacks. The spring-jack marked *J* is identical with the one in Plate IX Fig. 1. This figure, completing as it does the circuits of the double loop repeater, we take for granted that the reader perfectly understands and has clearly in mind. For ease in tracing, the conductors and loops are not only colored but distinguished from each other by dotting. The receiving apparatus is very simple. Beginning with the wedge at *J*, a current from the 'quad' or duplex set flows through the receiving side of loop No. 1 (dotted red), controls the transmitter *D* (or it may be a repeating sounder); thence to an extra jack and the ground at branch office *M*. A wire carrying a current supplied by the extra dynamo *Dy* is run through the post and tongue of transmitter *D*. which acts as a key, thence through a sounder and another jack to the ground at branch office *N*. In the sending apparatus, it is essential that the branch *M* on loop No. 1 should control the sending side of branch *N* on loop No. 2, and the pole-changer in the duplex set. So also, the branch *N* should control the sending side of branch *M*, and the pole-changer in the duplex set. And in each case, the transmitter or transmitters. through whose tongue or tongues the loop passes, must be kept firmly closed. If now the reader traces the wiring, he will see how this purpose is ingeniously accomplished. When ready for work, a current flows from the 'quad' or duplex set through the blue dotted wire by which it may be traced to the ground at *M*. A current also flows from the extra dynamo *Dy* along the solid blue line, through the

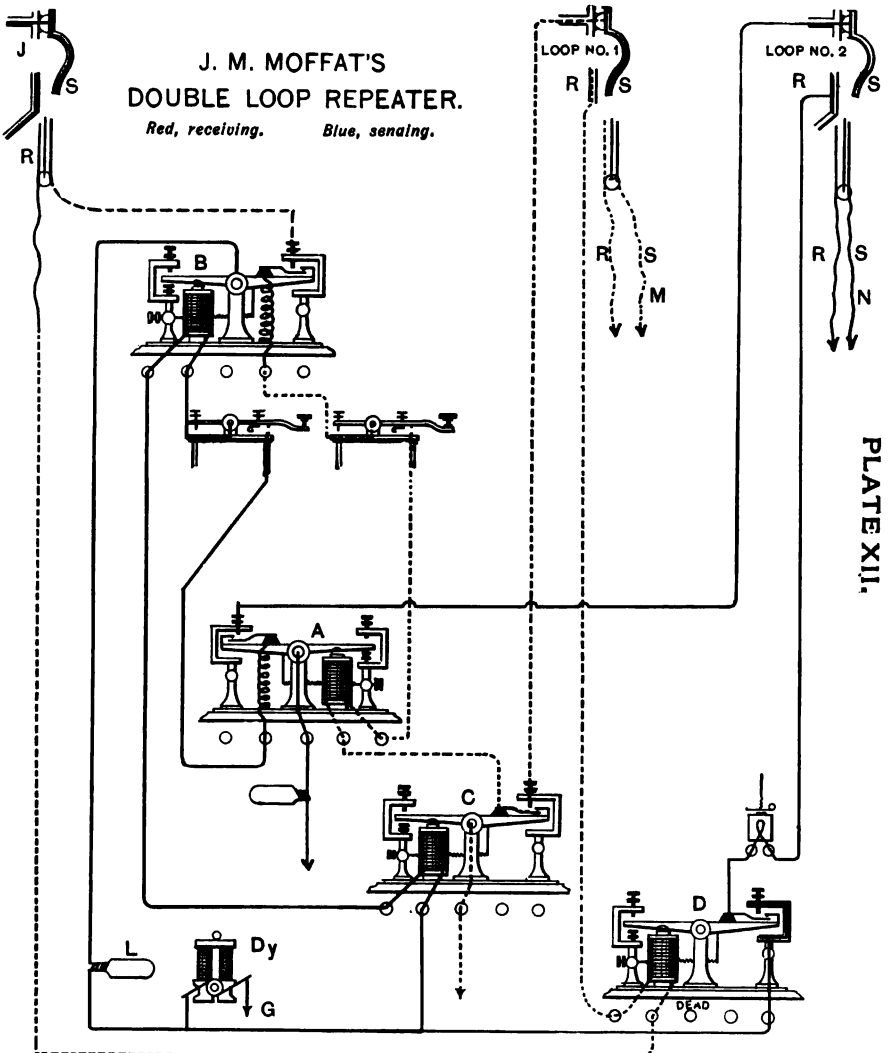

J. M. MOFFAT'S
DOUBLE LOOP REPEATER.
Red, receiving. Blue, sending.
J
S
R
B
A
C
D
Dy
G
L
LOOP NO. 1
R
S
M
LOOP NO. 2
N
DEAD

PLATE XII.

coils of *C* and *B* and the tongue of *A* to the ground at *N*. Open the key at *M*. Transmitter *A* is open; so also is the sending instrument at *N* and the pole-changer. But transmitters *B* and *C* are held closed by the solid blue line current, which now flows through the lever of transmitter *A* to an equating lamp; thence to the ground. Close the key at *M* and transmitter *A* is closed again. Let *N* open his key. Transmitters *B* and *C* are open; the former opens the pole-changer, the latter the sending side at *F*. But by the same movement of the transmitters *B* and *C*, the current from the extra dynamo *Dy*, now interrupted at *N*, flows through the equating lamp *L* to the lever and tongue of transmitter *B*; thence along the blue dotted wire through the lever of transmitter *C* to the ground, firmly closing transmitter *A* through whose coils it passes.

The arrangement of apparatus in the plate is not the one adopted in practice. For any one who, having mastered the idea of this repeater, wishes a diagram for testing purposes the following course is recommended: Take a sheet of paper two or three times the size of the plate; arrange the four transmitters thus:

A	*B*
D	*C*

Now draw the connections to correspond to the lettered transmitters. Complete the connections of the left-hand corner spring-jack by the diagram on Plate IX Fig. 1. He will then have the circuits entire.

THE DUPLEX REPEATER.

PLATE XIII FIG. 1 shows the conductors and connections by which two duplex sets may be made to 'repeat' into each other; that is:—the relay of one set controls the pole-changer or transmitter of the other. On either side of the drawing is the dynamo with duplex connections and spring-jack as shown in Plate IX. Into the spring-jacks are inserted the wedges of a double conductor, by which the sending side of one duplex set makes connection with the receiving side of the other. On the right-hand side a ground connection is substituted for the dynamo current. The current from the other dynamo divides at *A*, whence its course through the switch, instruments, and cords, to the ground can readily be traced by the colors. The two lamps in the cords are placed there to make the resistances of the circuits equal to that of the loops usually fed from this dynamo of which there may be a number.

Fig. 2 shows an arrangement of the duplex circuits for a similar purpose, but with chemical batteries. The receiving and sending sides are represented respectively by solid and dotted lines. Care must be taken so to dispose the batteries that they do not oppose each other. One pair of batteries, if strong enough, may suffice for the circuits; in which case the other pair may be replaced by a ground as in the case of the dynamo current.

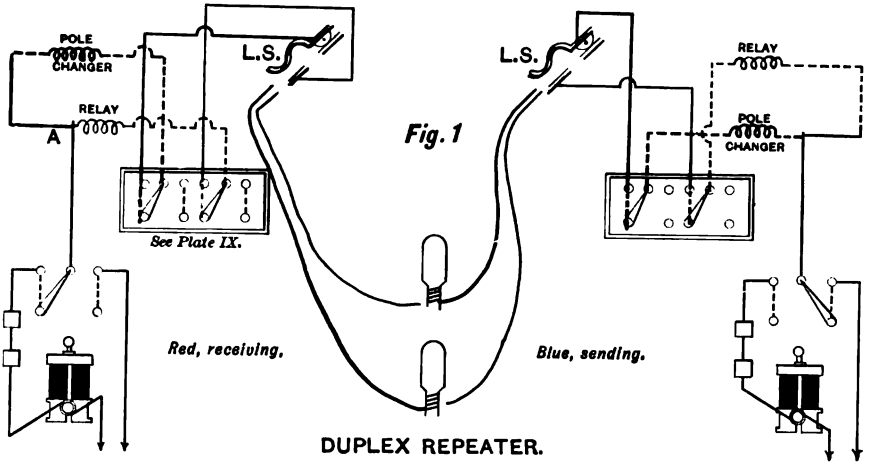


Fig. 1

DUPLEX REPEATER.

PLATE XIII.

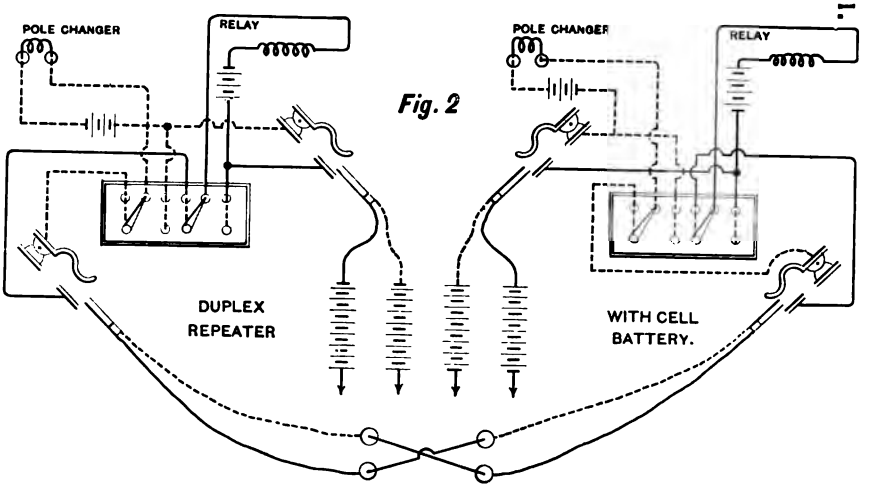


Fig. 2

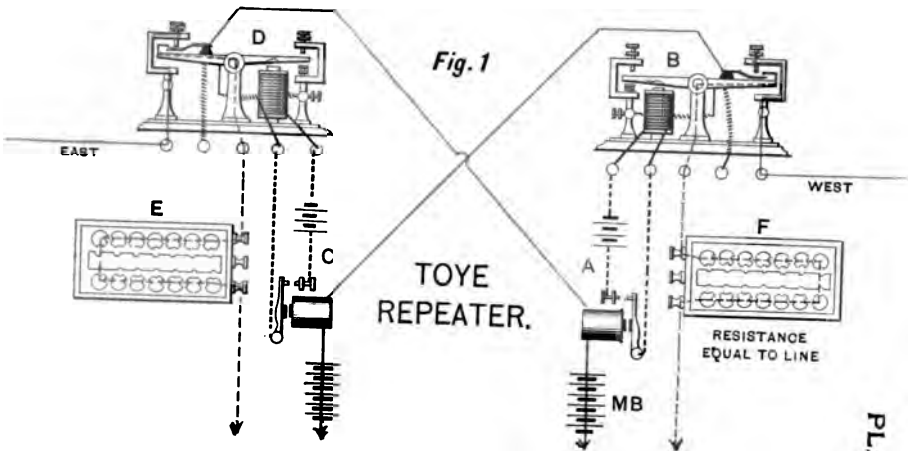


Fig. 1
D
B
EAST
WEST
E
F
C
A
TOYE
REPEATER.
RESISTANCE
EQUAL TO LINE
MB

PLATE XIV.

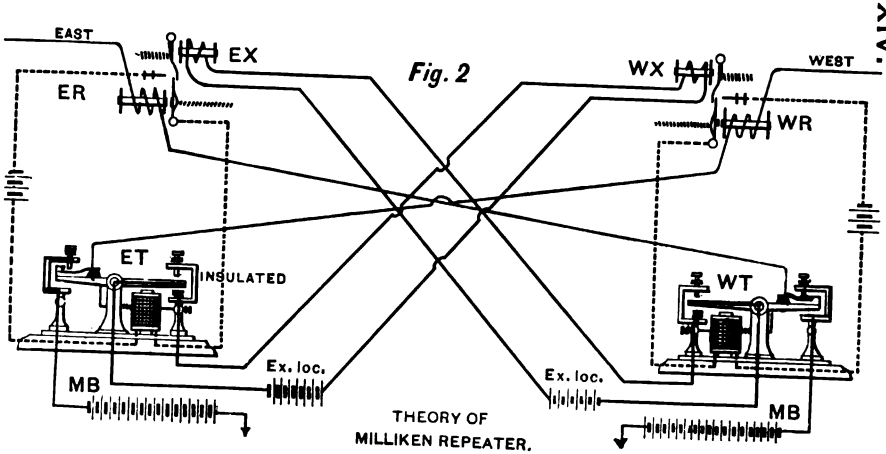


Fig. 2
EAST
EX
ER
WX
WEST
WR
ET
INSULATED
WT
Ex. loc.
Ex. loc.
MB
MB
THEORY OF
MILLIKEN REPEATER.

SINGLE LINE REPEATERS.

Up to this point we have shown that a duplex set may be extended to, and worked by, a single wire branch; by a double wire branch connection, or loop; by two loops in combination; and lastly it may be worked by another duplex set. Another use of the duplex, or one side of the quadruplex, set remains to be considered. It is that combination by which they are made to be controlled by, and repeat into, a single line of any workable length. This is done by aid of the ordinary forms of single-line repeaters, two varieties of which have held their ground amid a host of rivals as instances of the 'survival of the fittest.' These two are the Toye and the Milliken repeaters; the former, being the simpler of the two, we will describe first. It is represented in the diagram Plate XIV Fig. 1.

The apparatus consists of two main and two local batteries, two relays, two transmitters and two rheostats. Suppose the repeater to be at New York and that Boston (blue line) is sending to Buffalo (red line). Boston opens the relay *A* which controls transmitter *B*, the tongue of which, in connection with the post, acts as a key in the western circuit and opens it. This movement would also open relay *C*, transmitter *D*, and therefore the eastern line upon the sender, were it not for the device which is the feature of the repeater. When transmitter *B* opens, the tongue connects through the lever with a rheostat having a resistance equal to that of the line; thence to the ground. Relay *C* and transmitter *D* are thus kept closed and the eastern line kept intact. The action when the western station is sending to the eastern is similar. The advantage of this form of repeater is that it requires no special apparatus. The objections to it are that main batteries being necessary to its operation, it can be used only at terminal stations; and also, that by the action of the transmitter the batteries are kept constantly closed.

THE MILLIKEN REPEATER.

The pattern of repeater which may be considered the standard of the United States is shown, in its theoretical form, in Fig. 2. As already illustrated in the Toye repeater,

the essential feature of every form of automatic repeater is some device by which, when the sender on one line opens the instrument which repeats into the other, the first-named line shall not be opened on the sender.

In the Milliken repeater this device is the extra magnet controlled by an extra local and a strong retractile spring. Suppose, as before, that the repeater is at New York and that Boston (blue line) is sending to Buffalo (red line). Boston opens his key. This opens the relay *ER*, which opens the transmitter *ET*, the tongue of which, in connection with the post, acts as a key in the western circuit and opens it. This movement would also open relay *WR*, transmitter *WT*, and therefore the eastern line upon the sender, were it not that the (black line) extra local circuit *WX*, which passes through the lever and back post of transmitter *ET*, is now open; the pendent armature of the electro-magnets *WX* is released and, by the strong retractile spring, drawn against the upright armature of the relay *WR*. This keeps closed the transmitter *WT*, and, through its tongue and post, the eastern line also.

When Boston closes again, he closes relay *ER* and transmitter *ET*. The extra local circuit through this transmitter, being now closed, the pendent armature is drawn to the magnets, and the relay *WR* is held closed by the western wire which passes through the tongue and post of transmitter *ET*. The plain end of the lever of this transmitter is insulated from its post to prevent the interference of the distant western battery with the extra local circuit when the transmitter is open. The action of the repeater is the same when the west is sending to the east.

Plate XV represents, in detail, the actual connections of the Milliken repeater with machine currents. The reader who has familiarized himself with the theory of this repeater will have little trouble in tracing out the various circuits by means of the colors. There are six independent circuits, viz., the eastern main in solid blue; the western main in solid red; the two extra local circuits in dotted colors; and the two transmitter local circuits in dotted black. The function of all these and their mode of operation have already been explained. The cords go to the loop-switch; thence by flying cords to the main switch wedge; one side of which makes contact through a strip, peg, and disk with the battery; the other with the main line. The levers of the transmitters should be permitted only movement enough to break the current; and the tension of their springs should be moderate. The tension of the retractile spring of the pendent armature of the relay must be greater than that of the upright.

PLATE XV.

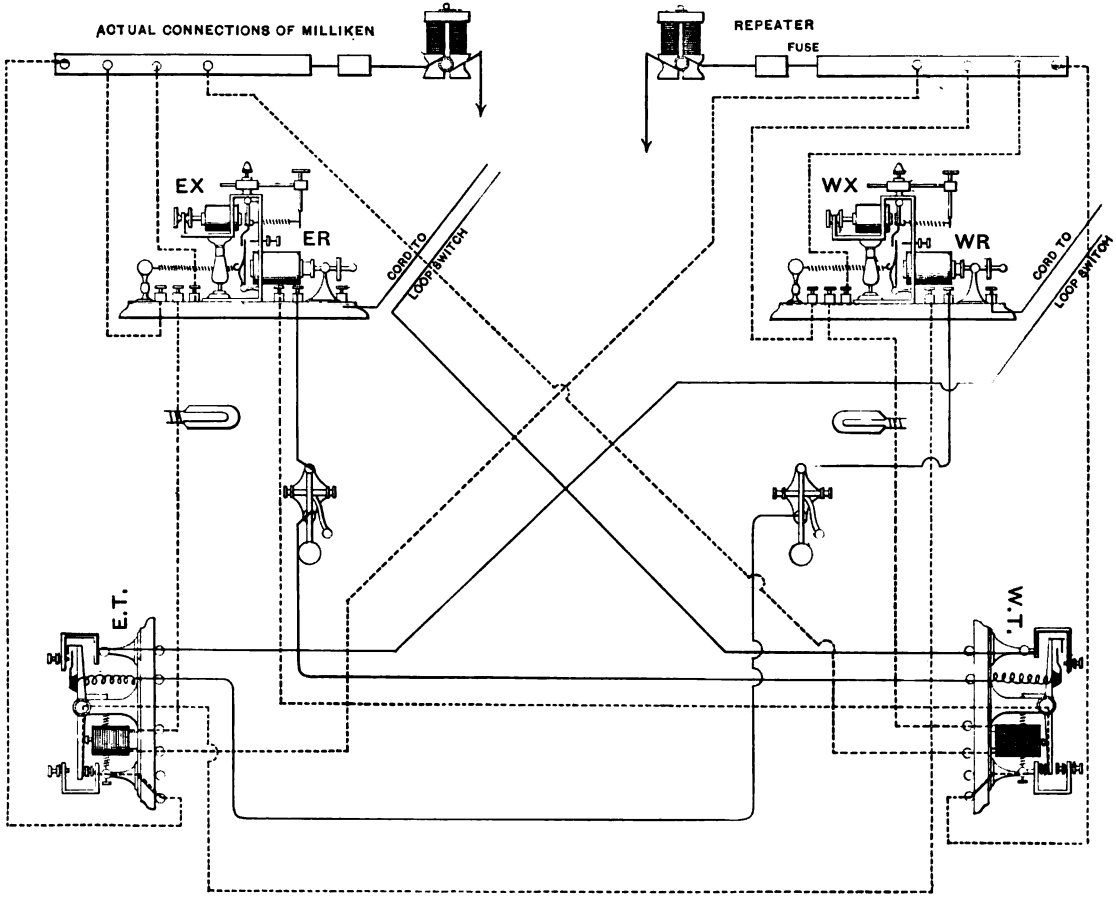
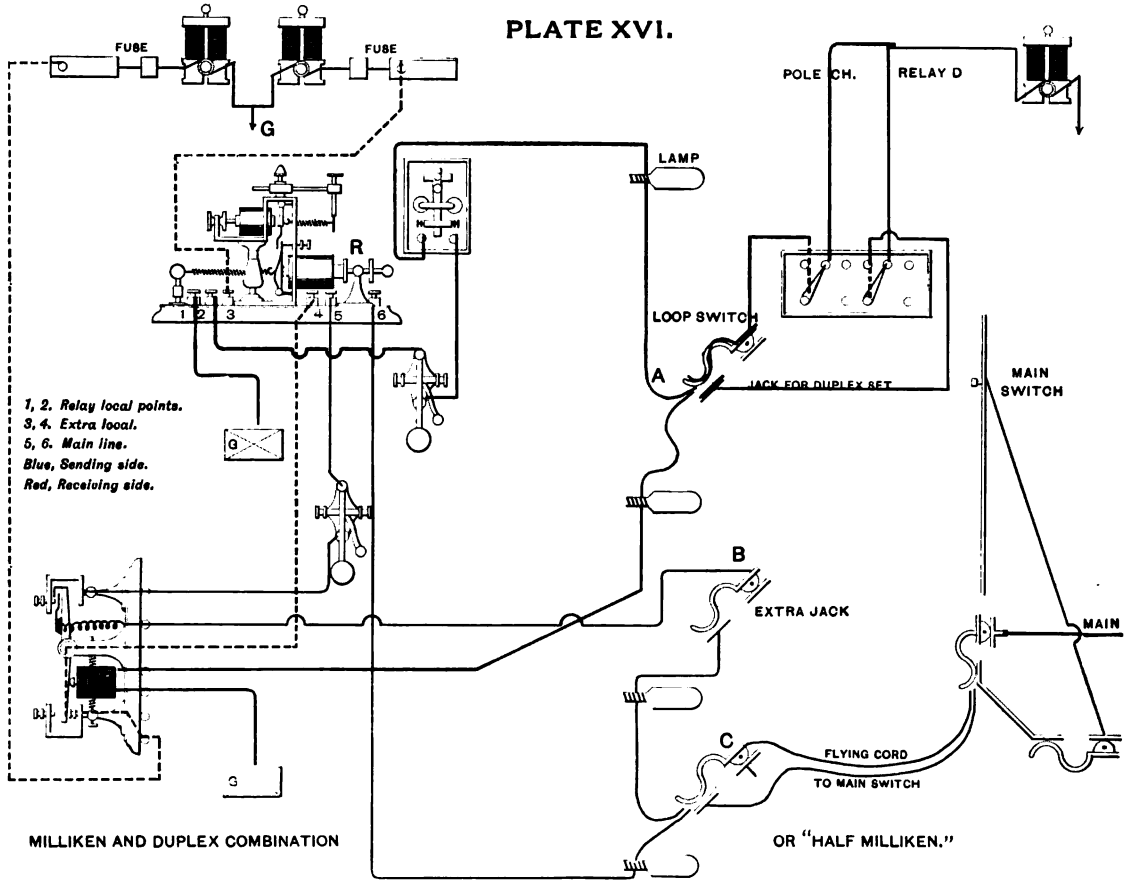

ACTUAL CONNECTIONS OF MILLIKEN
REPEATER
FUSE
EX
ER
CORD TO LOOP SWITCH
WX
WR
CORD TO LOOP SWITCH
E.T.
W.T.

PLATE XVI.



MILLIKEN AND DUPLEX COMBINATION

OR "HALF MILLIKEN."

THE HALF-MILLIKEN REPEATER.

PLATE XVI illustrates an arrangement for machine currents by which the offices on a single wire of considerable length may repeat into, i.e., receive and send on, a duplex or one side of a quadruplex set. The repeating apparatus consists of one half of the Milliken repeater just described, hence the name. The spring-jack *A* and the desk switch with its connections are identical with those in Plate IX Fig. 1. On the right is a section of the main switch, from which the battery and line are conveyed by a wedge and flying cord to spring-jacks *C* and *B* in the loop switch. In spring-jack *C* is inserted the wedge which carries the repeating relay, key, and transmitter circuit. Extra spring-jack *B* is for the insertion of an office or branch loop, when required. Suppose, as before, that Buffalo (red line) is sending to Boston (black line). He controls relay *D*, the points of which control the transmitter and, through the tongue and post, the relay *R* in the eastern circuit. Through the local contact point of relay *R* passes the blue-line circuit which, it will be seen, controls the pole-changer of the duplex set. When Buffalo opens, therefore, he would get his own signals back if it were not for the device already described, by which the pendent armature is at right moment drawn against the upright armature, holding closed the relay contact points and the pole-changer. When Boston breaks, the transmitter is closed; the extra local circuit (dotted red) is intact; the upright armature of relay *R* is free to move and work the pole-changer. Two lamps are inserted in the colored-line circuits to make their resistances the same as those of other circuits fed from the same dynamo. The two lower lamps are placed there to protect the repeating apparatus either from a near-by cross on the line or, from what is more common, the grounding by mistake of the loop which may be inserted in spring-jack *B*.

THE HALF-MILLIKEN (CHEMICAL).

PLATE XVII FIG. 1 shows the half-Milliken repeater arranged for chemical batteries. The circuit through the repeating relay points and the pole-changer is represented by the broken line. The others can readily be traced. Here, as elsewhere, the local batteries must be so disposed as not to oppose those led up through the wedge.

Fig. 2 represents an arrangement, in common use in newspaper offices, by which they may work their loops 'singly' or 'duplex' as required.

To work 'duplex' turn the switch levers in the drawing to the left. The left-hand cord of the wedge runs through sounder *A* to the ground and forms the receiving side. The right-hand cord runs through a key, through sounder *B* to the ground.

To work 'singly' turn the levers to the right. Sounder *A* is cut out. The wedge circuit is now by way of the key and relay, through the contact point of which runs the dotted line circuit controlling sounder *B*.

CALL-BELL IN DUPLEX CIRCUIT.

It is very essential to a multiplex repeater service to be able to summon attention at the repeating station without delay.

Through the kindness of Mr. E. E. Backus, of the Repeater Department at Lynchburg, Va., we are enabled to furnish a drawing of a call-bell device by Mr. H. C. Snead of the same office, which is in use throughout the South. A neutral relay is inserted in the duplex circuit, as indicated. The back contact points are placed in circuit with a vibrating bell instead of the usual repeating sounder. The home battery, of course, passes through the relay without effect. The relay is adjusted so that the effect of the distant battery keeps the armature closed. If the distant station goes on the ground, the armature is released, the local circuit is closed and the bell rings so long as the ground contact continues.

PLATE XVII.

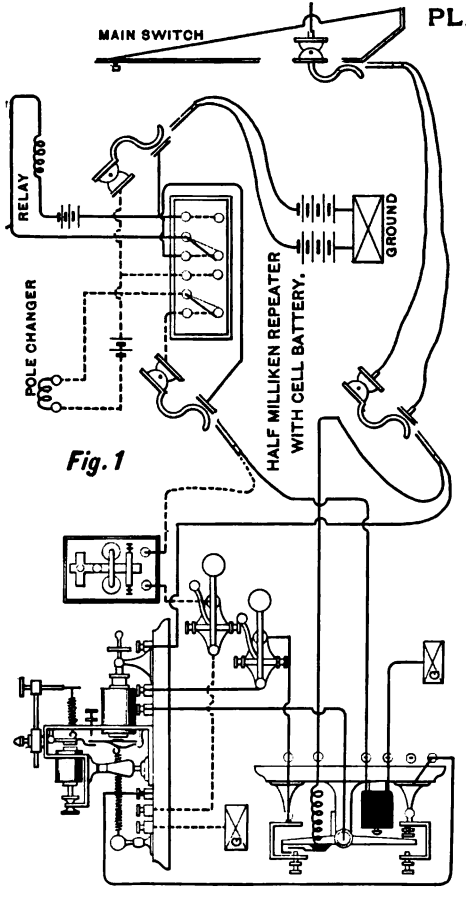


Fig. 1

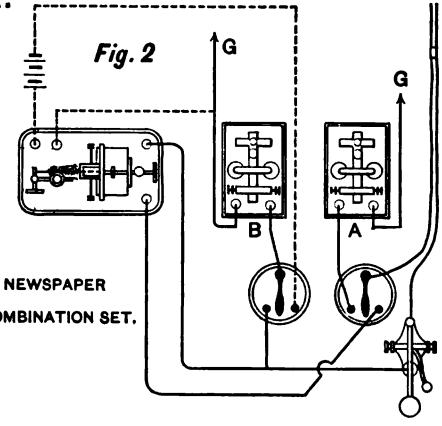


Fig. 2

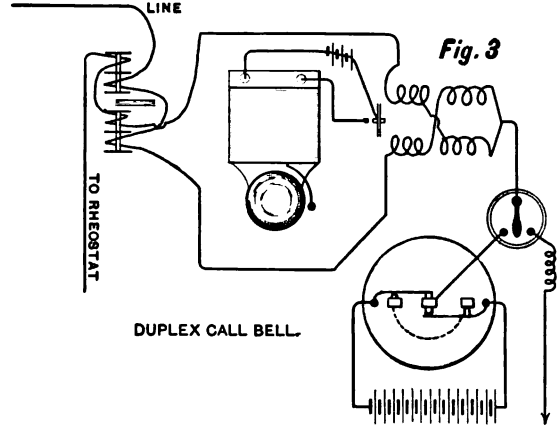


Fig. 3

THE LOOP SWITCH.

THE multiplex system was greatly extended and the general service improved by the introduction of the loop switch.

Its general purpose is twofold : (1) It permits the concentration of the multiplex system in one room under a few experts, and gives the control of the circuits to branch offices by means of loops, so called, but in reality two grounded wires. (2) It makes possible the interconnection of every variety of repeater known to the service, both with the multiplex sets and the air lines in the main switch. Its functions are analogous to those of a Central Office in a Telephone System. In the construction of the new loop switch at 195 Broadway five tiers of spring-jacks, in all three hundred and seventy-five in number, of the ordinary pattern are arranged one above another on nearly vertical shelves. These are the termini of the various flying loops (two wire conductors), 126 in number, terminating in wedges for insertion in the jacks of the main switch. To the loop-switch jacks also are led the desk connections of every multiplex set and of certain repeaters.

Through apertures in the switch desk are led the conductors from the branch-office loops, the newspaper loops, Milliken repeaters, intermediate batteries, and other apparatus terminating in wedges, the faces of which are insulated from each other.

The means of interconnection available under this arrangement between lines, repeaters, and multiplex sets renders the number of possible changes and conbinations very great. Before the adoption of the loop switch, branch-office loops were connected permanently to the desks, and the offices using the wire, in case of its failure, were obliged to remain idle until it was made good.

By means of the loop switch, when a circuit fails on which an important loop, like that of the Produce Exchange, is working, that branch can be immediately removed from the circuit and placed on another.

In Plate XIII Fig. 1 is illustrated how, by inserting the wedges of a duplex repeater cord into the spring-jacks of two duplex sets the local connections are so interchanged that the receiving side of one set has control of the sending side of the other ; and *vice versâ*.

With the additional aid of a double loop and half-Milliken repeater (see Plates XII and XVI) one duplex may be made to repeat into another, and into a single wire as well. In the latter circuit several single loops can be added, either at the extra spring-jacks of the loop switch, or at the main switch.

As an illustration of the combinations of circuits made possible by means of a double-loop repeater, duplex cord, half-Milliken and full-Milliken repeaters, suppose Chicago has a newspaper item for Boston, Albany, and Washington, and two "drop copies" for New York. Insert the wedge of the double-loop repeater in the Chicago duplex set. Take the wedges of a duplex repeater cord (Plate XIII). Put one in jack marked 'Loop No. 1' Plate XII, and the other in the spring-jack of the Boston duplex set. Take the two wedges of a half-Milliken repeater. Insert the local connection wedge in the jack of the double-loop repeater (marked 'Loop No. 2'). Insert the line wedge (see Plate XVI) in the jack of a flying loop, the wedge end of which goes in the Albany single wire at the main switch. Take the two wedges of a full Milliken. Place one in the Albany circuit and the other in the jack of a flying loop, the wedge end of which goes in the Washington single wire at the main switch.

The local connections of the Chicago set and the double-loop repeater being in series, every signal from Chicago will be reproduced in each circuit controlled by this repeater, i.e., the Boston duplex set through the duplex repeater cord, and the Albany circuit through the half-Milliken repeater. The Albany circuit in turn controls the Washington circuit through the full-Milliken repeater. Two newspaper loops for the New York 'drop copies' can be inserted in the extra jacks, either in the loop or main switch. Thus Chicago can simultaneously transmit to New York, Boston, Albany, and Washington.

Extra batteries, an ammeter, and other apparatus for testing, together with a number of call wires, complete the accessories of the loop switch.

PLATE XVIII.

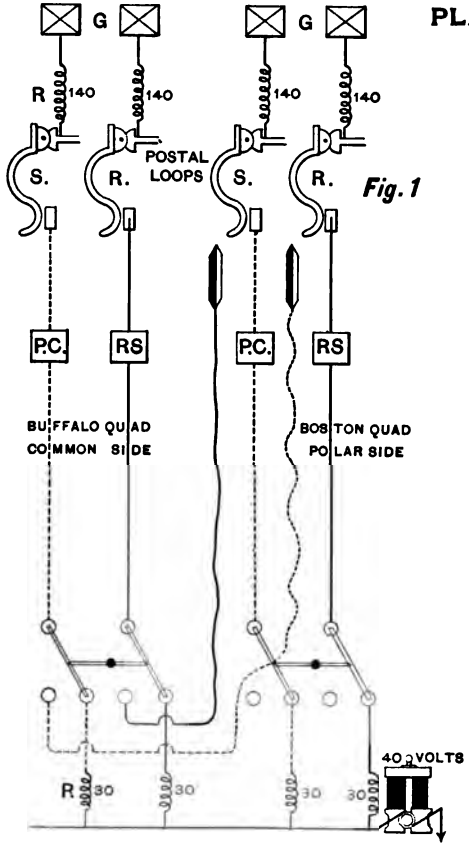


Fig. 1

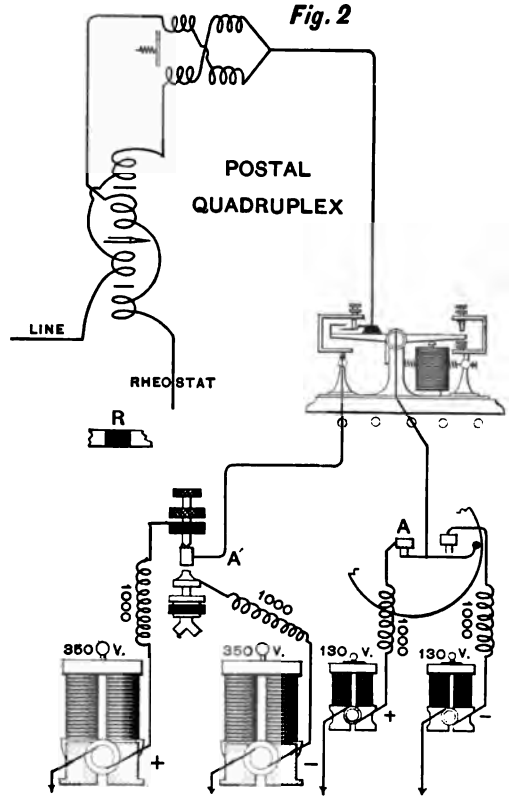


Fig. 2

THE POSTAL TELEGRAPH LOOP SYSTEM.

PLATE XVIII FIG. 1 illustrates the multiplex loop system with dynamo current as recently installed in their St. Louis office. The diagram shows the ordinary local circuit; the arrangement for inserting branch wires; the method of repeating from one side of a quadruplex into another; and the mode of inserting branch wires in the repeating circuits, without the metallic loops required in other systems. The machine current is distributed through resistance coils of 30 ohms each to the right-hand disks of the double three-point switches; thence, when the levers are to the right, through the instruments and spring-jack, to the ground through 140 ohms resistance.

The branch wires (not shown) terminate at the board in wedges insulated on one side, which, when properly inserted in the jack, ground the circuit at the branch instead of through the jack. For repeating purposes, the left-hand disks of the three-point switches also terminate in wedges insulated on one side. Insert the sending and receiving sides of one circuit into the receiving and sending sides, respectively, of another; turn the lever of the first circuit from the dynamo to the wedge disks and the repeating arrangement is complete. To connect the common and polar sides of the Buffalo and Boston quads, insert the wedges as in the diagram and turn the levers on the Buffalo quad to the left. The Boston side relay now controls the Buffalo side pole-changer and *vice versâ*. And, in addition, two wedges grounded at a New York branch office may be inserted in the jacks on the Buffalo side and have the use of the duplex circuit along with the terminal offices. In other systems, this would require metallic loops.

Fig. 2 represents the latest development in the application of dynamo current to quadruplex work. This system was recently installed in the St. Louis office of the Postal Telegraph Company under the supervision of its inventor Mr. F. W. Jones, the company's electrician. Two machines furnish 130-volt currents of opposite polarity for the 'short end;' and two others 350-volt currents for the 'long end.' The pole-changer, which is the essential feature of the system, is an ingenious combination of the 'clock-face' and 'walking-beam' patterns of the Western

Union. The lever is in two sections, insulated from each other, after the manner indicated by the bar *R*. In the diagram *A* and *A'* represent the front and back ends, respectively, of the lever of an open pole-changer thus divided. It can readily be seen that when the transmitter is open, the wire leading from *A'* to the post is dead ; and only the reversals of the 130-volt machines go to the line, through the lever and tongue of the transmitter. Close the transmitter, and the wire leading from *A* to the lever is dead ; and the reversals of the 350-volt machines go to the line. In both leads from both potentials resistances are inserted to lessen the tendency to spark and avert the danger from short-circuiting.

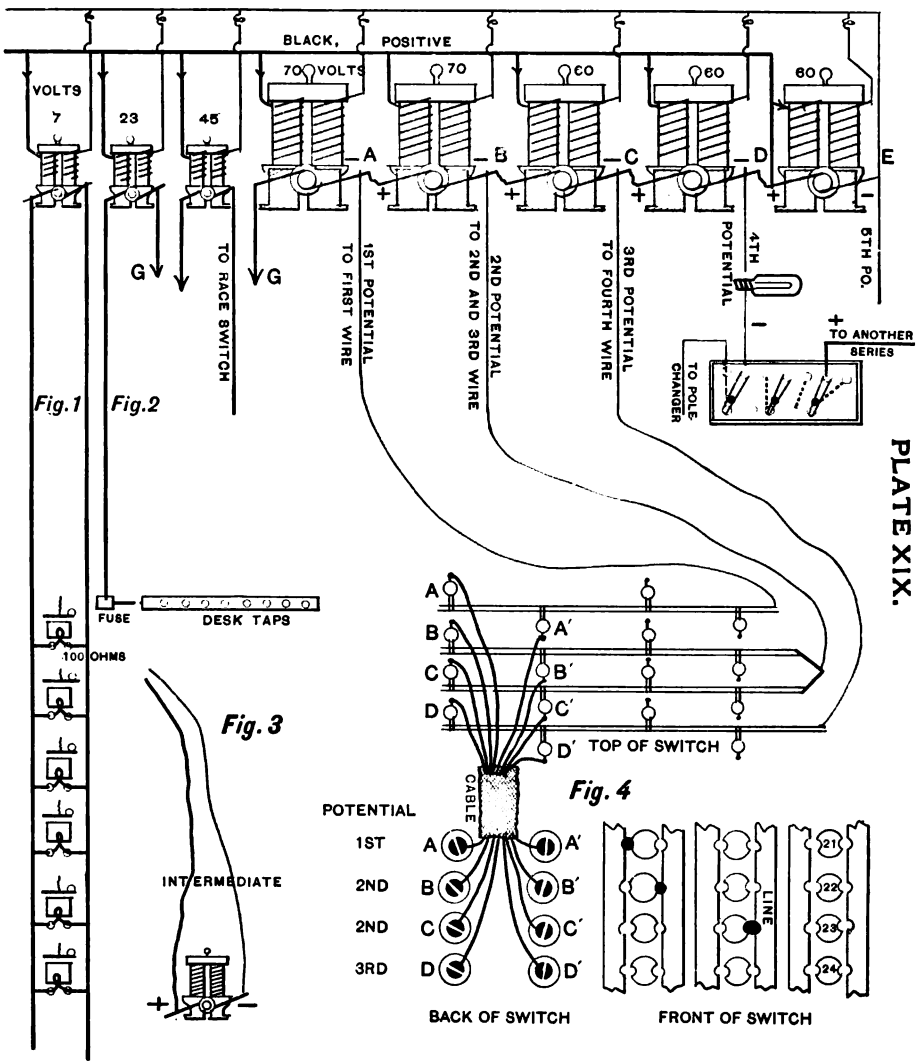

BLACK, POSITIVE
VOLTS
7
23
45
70 VOLTS
70
60
60
60
A
B
C
D
E
G
G
TO RACE SWITCH
1ST POTENTIAL
TO FIRST WIRE
2ND POTENTIAL
TO 2ND AND 3RD WIRE
3RD POTENTIAL
TO FOURTH WIRE
4TH POTENTIAL
5TH PO.
TO ANOTHER SERIES
TO POLE CHANGER
Fig.1
Fig.2
FUSE
DESK TAPS
100 OHMS
Fig. 3
INTERMEDIATE
A
B
C
D
A'
B'
C'
D'
TOP OF SWITCH
Fig. 4
CABLE
POTENTIAL
1ST
2ND
2ND
3RD
BACK OF SWITCH
FRONT OF SWITCH
LINE
21
22
23
24

PLATE XIX.

CURRENT DISTRIBUTION.

In the reconstructed Western Union office in New York, dynamo currents replaced all others to such an extent that, except for testing purposes, not a cell of battery now remains. The machines which supply the current are in the cellar under the Broadway end of the building.

For the supply of main-line currents there are three gangs of five dynamos in series—one of each polarity; the third being a relief gang and reversible, so that it may supply currents of either polarity. The fifth machine, having less work to do than either of the others, is made to furnish a 60-volt current to excite, in multiple, the fields of all the machines in its own gang. As a matter of economy in wiring, there are connected in multiple in the same circuit the fields of six smaller machines forming three pairs; one supplying 7-volt currents for locals; another 23-volt currents for loops; and another 45-volt currents for city and short-line service.

Of these lower-voltage machines only one of each pair is in use at a time; so that the working gang consists of 8 machines, with field coils in multiple, as represented in the diagram.

Fig. 1 shows the two leads from the 7-volt dynamo for locals, with the sounders in multiple, on the same principle as lamps for incandescent lighting. The armature resistance of this machine is very small. For the purpose of illustrating the principle of sounders arranged in multiple take, for the sake of simplicity, a 4-ohm sounder and an E. M. F. of 1 volt. The armature resistance is disregarded. These sounders require a current strength in the circuit of $\frac{1}{4}$ of an ampère properly to magnetize their cores.

If, in Fig. 1, all the sounders in circuit were open except one, the circuit would be completed through that one and the resistance would be 4 ohms. Then because $C = E \div R$, $1 \div 4 = \frac{1}{4}$ ampère. If two sounders are closed, the current would have two paths and the resistance (according to the rule for finding the joint resistance) would be 2 ohms. Our formula now gives us $1 \div 2 = \frac{1}{2}$ ampere; but, as the current divides equally between the two sounders, each

will still have $\frac{1}{4}$ ampere of current. This, of course, calls for more current from the dynamo, which must be wound to furnish all that may be required.

To find the joint resistance of a circuit composed of two or more lamps, or sounders, of equal resistance: divide the resistance of one lamp, or sounder, by the number in use. If you close 100 4-ohm sounders the joint resistance will be $4 \div 100$ or $\frac{1}{25}$ of an ohm; then the current will be $1 \div \frac{1}{25} = 25$ ampères. This will divide equally among the 100 sounders, and we still have $\frac{25}{100}$ or $\frac{1}{4}$ of an ampere for each instrument.

Owing to small losses from minute resistances in the wire connections, and the ratio of the armature to the joint resistance, you would not, in practice, get as close a result as given above; but, as a matter of fact, over 100 sounders were satisfactorily worked from a 1-volt machine at 195 Broadway, soon after the fire.

The sounders in actual use for all single wires have a resistance of 100 ohms each; and, as stated, are worked by a 7-volt current. This is believed to be superior to the 4-ohm and 1-volt arrangement. The increase in the number of turns in the 100-ohm sounder makes the magnetizing force nearly the same in both; but it will act more quickly on the cores of the finely wound instrument. The high resistance in the coils greatly weakens the extra, or opposing, currents; so that the retardation due to these currents is more easily overcome.

Fig. 2 shows the current led from the 23-volt machine, through a fuse, to a row of thumb-screws under the desk convenient for tapping. In Plate IX Fig. 1 and in Plate XV may be seen examples of their use for loop and extra local circuits.

Fig. 3 is an intermediate battery supplied by a small dynamo, of which there are 30 in the Western Union plant. These deliver currents of from 50 to 125 volts, each machine having attached to it a one-half ampère lamp connected permanently in the circuit. From either brush, a conductor runs up through the desk of the loop-switch and terminates in a wedge. From the loop-switch jacks they may be conveyed by flying loops to the main switches for insertion in the circuits, as required.

Of the different gangs of large machines, the drawing represents the negative; the positive brush of the first machine being grounded. The first and second machines have a potential difference of 70 volts each; and the third, fourth, and fifth of 60 volts each. As each additional one adds its electro-motive force, a lead from the brushes *A*, *B*, *C*, *D*, *E* will represent 70, 140, 200, 260, and 320 volts; or,

as they are called, the 1st, 2d, 3d, 4th, and 5th potentials. The 1st, 2d, and 3d potentials (the red conductors) terminate in the operating room in bus-bars, placed directly over the switches in the manner represented. The lamps on the different bus-bars have a resistance of two ohms per volt. Their purpose is to prevent injury, through overheating, to the armature coils of the dynamos in case of short-circuiting, or a near-by ground. They are held in sockets, one terminal of each connecting with its bus-bar (as shown on the right); and the other terminal, as shown on the left of Fig. 4, runs through a short cable to a brass rod which, on the front of the switch, is a segmented disk. Each lamp connects with one disk only, but each row of disks is connected horizontally at the back of the board. One horizontal row of disks is assigned to the first potential current; two rows to the second; and one to the third. These rows are numbered, respectively, 21, 22, 23, and 24 in a switchboard containing 30 horizontal rows, the last row being a ground wire. Most of the wires are worked on the second potential. It has, therefore, two rows of disks assigned to it, so as not to feed two wires through one lamp. Whenever a lamp is seen to glow, the wire chief knows at once that the wire connected to the strap thence to the disk by a peg, is grounded near by. Dynamo leads of only one polarity are connected with any one switch. The 4th and 5th potentials are not run to the main switch, but to a separate bank of lamps, whence they are conducted to the familiar three-lever switches (shown in the diagram) on the duplex and quadruplex desks.

WHEATSTONE AUTOMATIC DUPLEX.

PLATE XX illustrates the essential parts and connections of the Wheatstone Automatic Duplex System, which may be regarded as an electro-mechanical combination for increasing the carrying capacity of wires.

A complete set of apparatus comprises a transmitter, perforator, and receiver, of which but a very brief description need here be given.

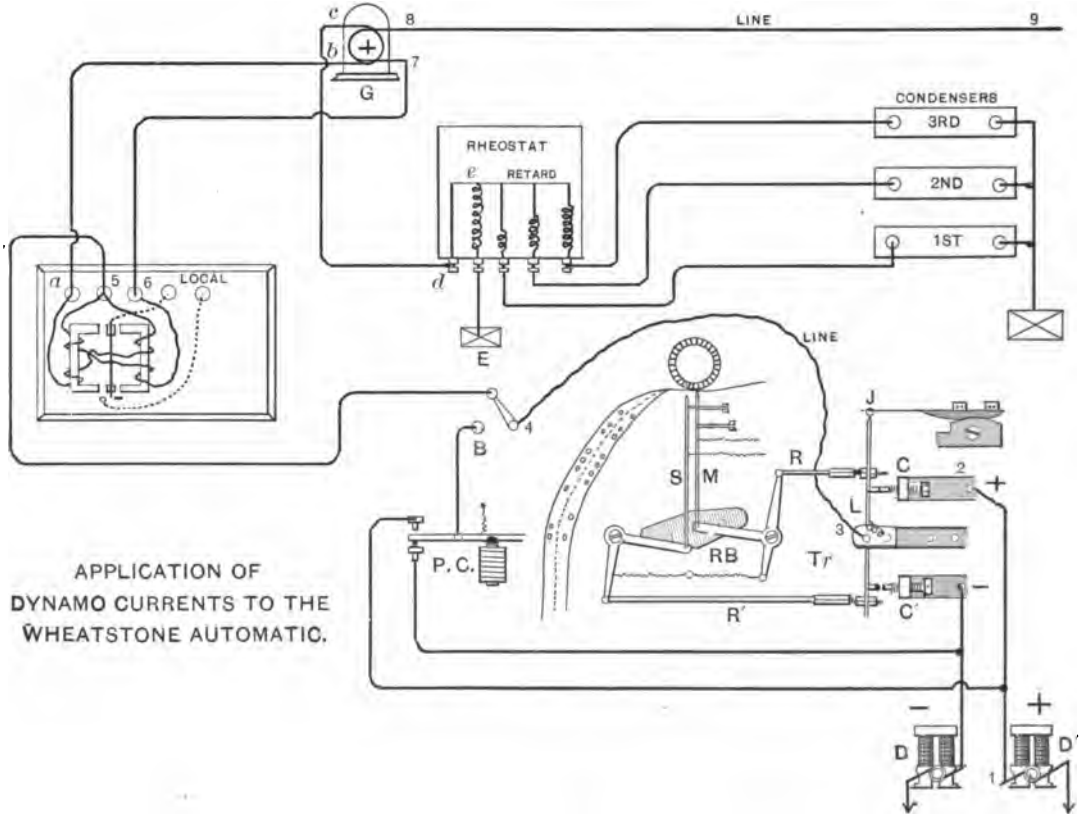
The instrument *Tr* in the drawing is the transmitter used for automatic signalling, while a modified form of pole-changer, P. C., serves for ordinary hand working; the switch *B* effecting the desired changes from one to the other.

The construction of the transmitter in its electrical details has been somewhat modified recently, with a view to the application of dynamo currents to fast-speed working. This has been accomplished by substituting for the commutating disk previously employed, a current-reversing device on the principle of the ordinary "walking-beam" pole-changer, which will be readily understood by reference to the diagram.

The necessary changes in the polarity and duration of the line currents are made by the transmitter under the control of the punched paper, which is represented as passing through the transmitter in the diagram. This paper is prepared by means of the perforator (not shown), which consists essentially of a series of small steel punches that cut holes at proper intervals in the paper whenever the necessary pressure is applied by the depression of either of the three keys with which the apparatus is provided. The particular function of the perforated slip is to determine the order, and regulate the duration of the currents which flow to line. When there is no paper running through the transmitter, the latter simply transmits a series of reversals, or currents of opposite polarity and regular frequency to line; but the paper slip interferes with this regularity by lengthening the dynamo contacts at the proper intervals.

The transmitter mechanism is set in motion by turning switch *B* to the right. The rocking-beam *RB* then imparts an up-and-down movement to the needles *S* and *M*, and a vibratory motion to the upright lever *L*, by means of the

PLATE XX.



APPLICATION OF
DYNAMO CURRENTS TO THE
WHEATSTONE AUTOMATIC.

rods RR'. This lever being connected with the main and artificial lines in the manner common to all duplex circuits, and the posts CC' attached respectively to the positive and negative dynamo machines D, D', a series of signals varying in length and direction may be transmitted to line. Should the needle M for instance, in its upward stroke, pass through a hole in the punched slip, lever L will be permitted to make contact with the positive dynamo through stop C, and a marking current will traverse the line wire. If this be immediately followed by a corresponding action on the part of needle S, the lever will be brought into contact with the negative dynamo through post C', and a spacing current will flow. These two currents of opposite polarity will cause a dot to be recorded on the distant receiving apparatus.

A dash, on the other hand, is formed by continuing the marking current to line for a longer period than that necessary for a dot. This is effected by the unpunched part of the paper, which checks the upward play of needle S, and retains the lever in contact with the marking dynamo post until the spacing needle finally finds a perforation to pass through, when it reverses the current.

The small jockey-wheel J, which presses upon the upper portion of lever L, prevents the latter from breaking away from either of the dynamo posts with which it happens to be in contact during the formation of the signals.

The receiver, on the left of the diagram, consists of a very delicate form of polarized relay, whose armature responds to the rapid reversals of the distant transmitter and causes signals to be recorded in ink upon a slip of paper provided for the purpose.

G is a polarized galvanometer for balancing with, and is of considerable service in detecting and locating transmitter, battery, and line variations. If, for example, the alternating currents sent out by the distant transmitter differ in strength, or are unequal in duration, the galvanometer will show a 'bias,' the deflection on one side representing a 'marking,' and the opposite deflection a 'spacing' bias. Should the batteries be short circuited or open at the distant office, the needle will stand at zero in the one case, and in the other will deflect to some point about midway between zero and the angle produced by the full strength of the received current; while a disconnection, ground, swing, and most of the other troubles experienced in working will each produce upon the galvanometer its characteristic effect, which only requires some practical experience in order to be properly interpreted.

The course of the outgoing current in the position as-

sumed by the transmitter may be traced by following the numerals from 1 to 5, at which latter point the current divides through the coils of the receiver. The path then taken by the main line portion continues from 6 to 9, while the letters *a* to *E* indicate the course pursued by the compensating part of the current. At the point *e* which is the beginning of the artificial line, a portion of the current is diverted through each of the retarding coils into the condensers, all of which are placed in parallel, and form a shunt around the regular balancing resistance.

The method of taking an ordinary line balance consists in first asking the distant office to run his transmitter. The artificial line is then adjusted in the usual way until the galvanometer needle remains indifferent to the outgoing hand signals.

Any static effects that remain may be eliminated by running the home transmitter, and regulating the condensers and retarding resistances until the incoming reversals or characters come clear and legible.

A perfect static balance is an important consideration in rapid working, and a good way to attain it is as follows: Having first asked the distant office to remain quiet, put a strong marking bias on the receiver, start it running, and at the same time run the transmitter. If the balance is disturbed the slip will show a greater or smaller number of reversals, which increase in size and frequency as the disturbance becomes more marked, but grow light and less numerous as the equation becomes more perfect. Adjust the condensers and retarding resistances until the dots entirely disappear, and then gradually remove the bias from the receiver. Should any dots reappear during the latter operation make further compensation until they are finally removed. If a repeater is in circuit it will be well while making these adjustments to have the circuit divided there, otherwise it would not be possible to secure a thorough compensation in case the section of line beyond the repeating station chanced to be out of balance.

Generally speaking, the first condenser requires a higher capacity than the second, which in turn needs more than the third. The retarding resistances on the other hand are usually varied in the reverse order; but the conditions met with in actual working oftentimes call for totally different methods of regulation.

If, for instance, the regular wire be patched near the home station with a smaller wire of high resistance, it will cause the line to discharge its static electricity more copiously at the distant end. This will necessarily leave a smaller quantity to be neutralized by the home condenser,

which must not only be reduced in capacity, but should also have its discharge retarded to an extent corresponding with that of the main line discharge.

The opposite of this course would require to be taken provided the patch were made at the remote end of the line; for in that case a greater static flow would be forced through the home apparatus, and a corresponding increase in condenser compensation would be necessary to meet it.

In wet weather, when the static discharge from the line is less than in dry weather, the condensers require less capacity; especially the first of the series which, together with its retardation resistance, may be, under such conditions, reduced with advantage.

Familiarity with the make-up and general condition of the wire is an invaluable aid towards effecting sure and speedy balances under most conditions of working.

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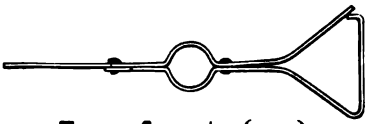

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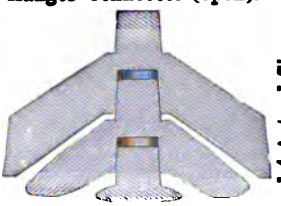

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